



Planning Public Transport

Good practice guide for course 13120

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Planning Public Transport

Good practice guide for course 13120



Autumn 2009
Department of Transport
Technical University of Denmark

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Preface

This good practice guide is composed for the master course 13120 Public Transport Planning held at the Department of Transport, Technical University of Denmark. It is intended to use as guide in the different planning aspects and assignments of the course.

Since the course is about the planning of new public transport infrastructure this guide also focuses on the planning of new infrastructure. Furthermore, the new infrastructure in the course is expected to be a light rail and even though this guide aims at being general for public transport some of the issues evidently become more relevant for light rail.

A light rail system is chosen as focus because light rail systems generally have higher impacts in the traffic modeling than busses and are more challenging in the planning than urban rail and metro. This is emanated by the assumption that a capability for planning light rail inevitable will enable a capability for planning both bus and rail.

The guide is build as a full sketch investigation of a new public transport project ranging chronological from project clarification to physical and timetable planning to traffic modeling and project appraisal. The same steps that are expected to be fulfilled in the course.

In the course the public transport project that is investigated is a real life relevant project. In this guide the project and the area of interest are fictitious in order to illustrate the planning issues better but also to avoid direct comparison.

The theory of the different planning issues is described and examples are illustrated by figures and tables.

Finally, I will like to acknowledge everyone who has participated in the process of creating this guide. It is my intention to update it continuous so corrections, comments and/or ideas are very welcome.

Autumn 2009

Jonas Lohmann Elkjær Andersen

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1 General

Beginning an investigation of a brand new public transport infrastructure requires both background information about the existing situation and localization of existing traffic problems. It also requires definitions of the data available for the investigations. Most of this is, therefore, relevant to place at the earliest stage of the investigation. However, also the preliminary investigations (chapter 2) are part of the general preconditions for investigating a public transport project.

1.1 Introduction

It can be a good idea to present the project frame and superior corridor intentions in an introduction. It may also be necessary to present a delimitation of aspects it was not possible to investigate and a reading guide for overview and guidance to the actual investigations.

1.2 Area of interest

The area of interest is generally the area that will be affected by the new public transport infrastructure. Usually the area of interest is limited by the available data but if that is not the case some delimitation may be needed. The area of interest can be a very large area that often is naturally coherent in jurisdictional structure and/or commuter patterns. Such an area may, due to people travelling in all directions, very well be a metropolitan area like the Greater Copenhagen Area.

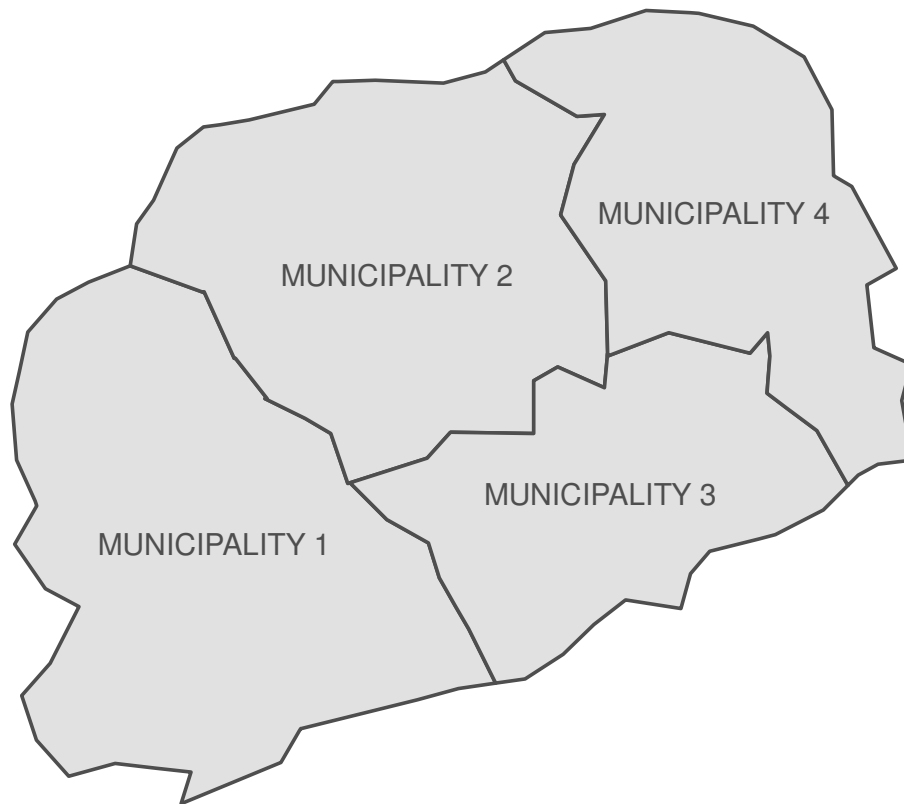


Figure 1.1 – Area of interest with jurisdictional structure

If the area of interest is a very large area and the corridor of the new infrastructure is a lot smaller map zooms can be relevant.

1.3 Existing public transport

The existing public transport in the area of interest should be described. This is to obtain an understanding of the system in the area of interest and to know how a new line will fit in. A list of all types of public transport and their particular functions in the area of interest is preferable. Also a map showing the main lines is good practice as seen in figure 1.2

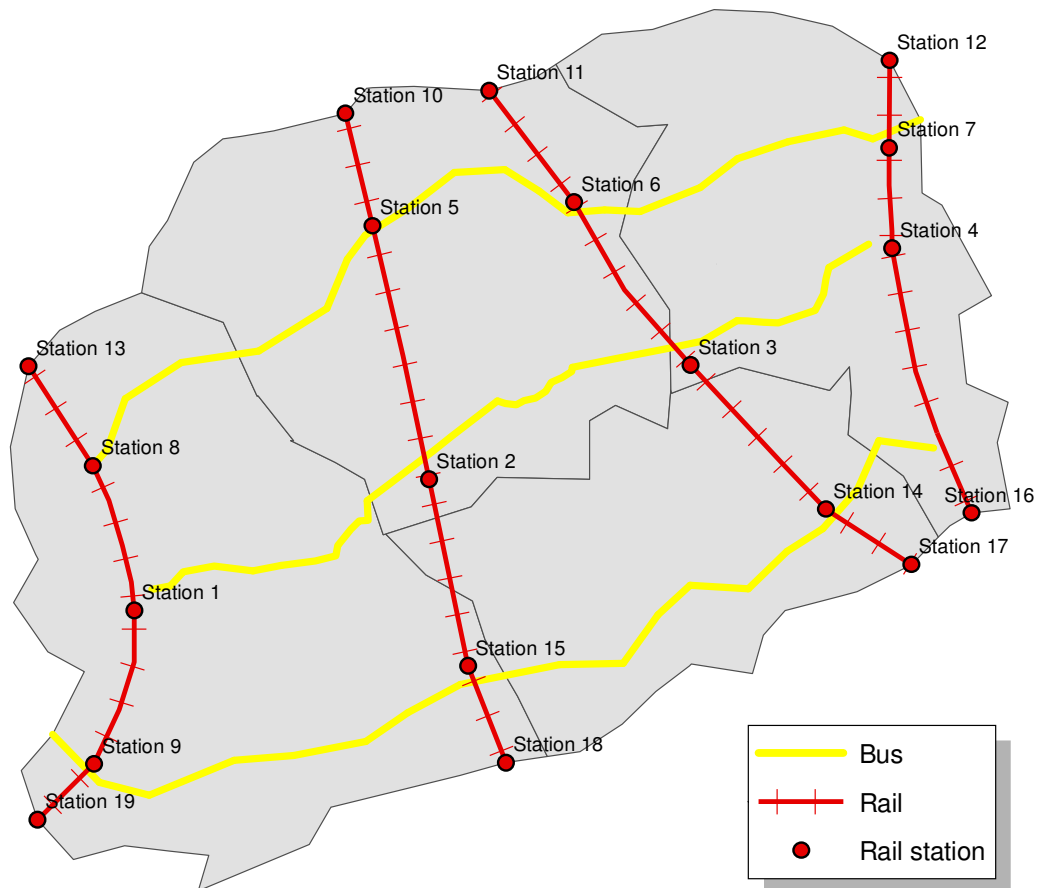


Figure 1.2 – Existing public transport in the area of interest

The existing transport provides background for identifying general traffic problems in the area of interest.

1.4 Data for investigations

It is important to define the data that is available for the investigations. This is mainly based on travel demand information and traffic modeling. Especially the zonal structure is important to present (see figure 1.3).

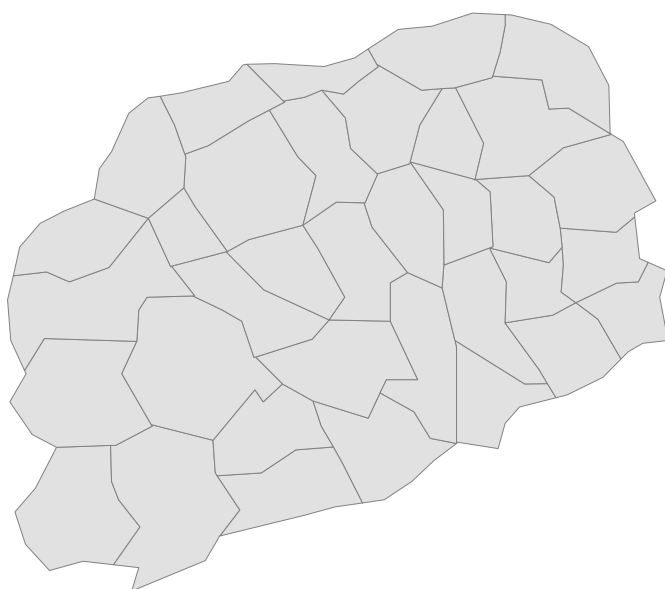


Figure 1.3a
Model zonal structure – used
for traffic modeling and
superior analysis



Figure 1.3b
Land use zonal structure –
used for detailed analysis

Other data sources and maybe even important software can also be introduced.

2 Preliminary investigations

The preliminary investigations are used to investigate the existing conditions in the area of interest and examine if there is a need for high quality public transport. The Preliminary investigations should be used to define a geographical corridor for the further investigations of the new public transport service. The preliminary investigations can be based on demographic and socio-economic data e.g. combined with station vicinity as well as existing travel and travel time e.g. by regional accessibility and mobility.

2.1 Regional accessibility and mobility

Regional accessibility and mobility can be shown in many different ways. What is good practice to show depends on determined relevancy and the conditions of the focus area. However, it is always a good idea to show some travel volume issues (from trip matrix), some travel time issues (from level-of-service (cost)matrix) and some comparisons between private and public transport for both accessibility and mobility. Some examples are given in figure 2.1 – 2.3.

Figure 2.1 shows how trip matrix data can be used to illustrate the public transport share of motorized traffic going to and from all zones.

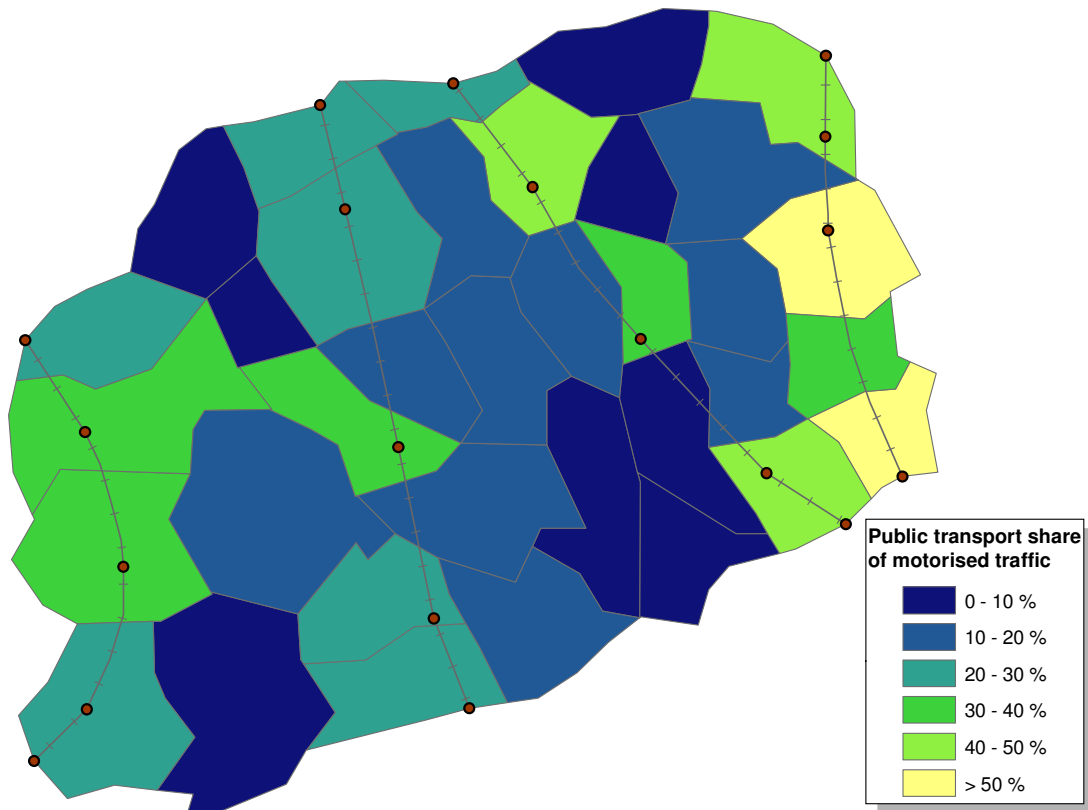


Figure 2.1 – The public transport share of the motorized traffic to and from all zones (Trip matrix data)

Figure 2.2 shows how trip matrix data can be accumulated to larger zones to get an overview of the public transport travel between municipalities.

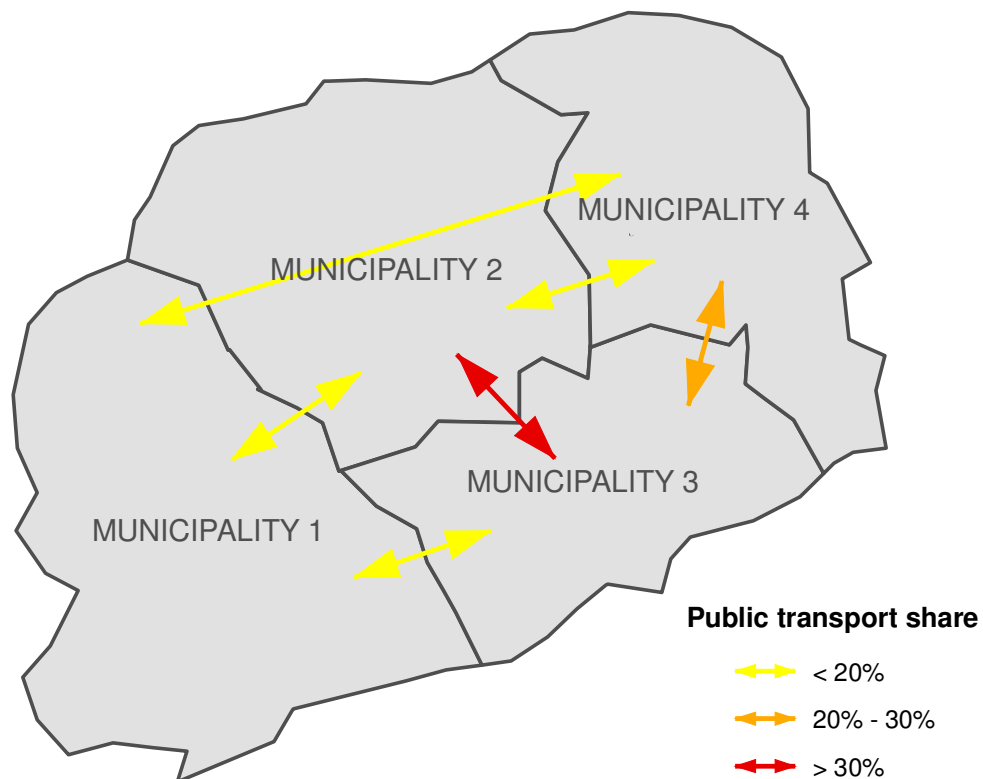
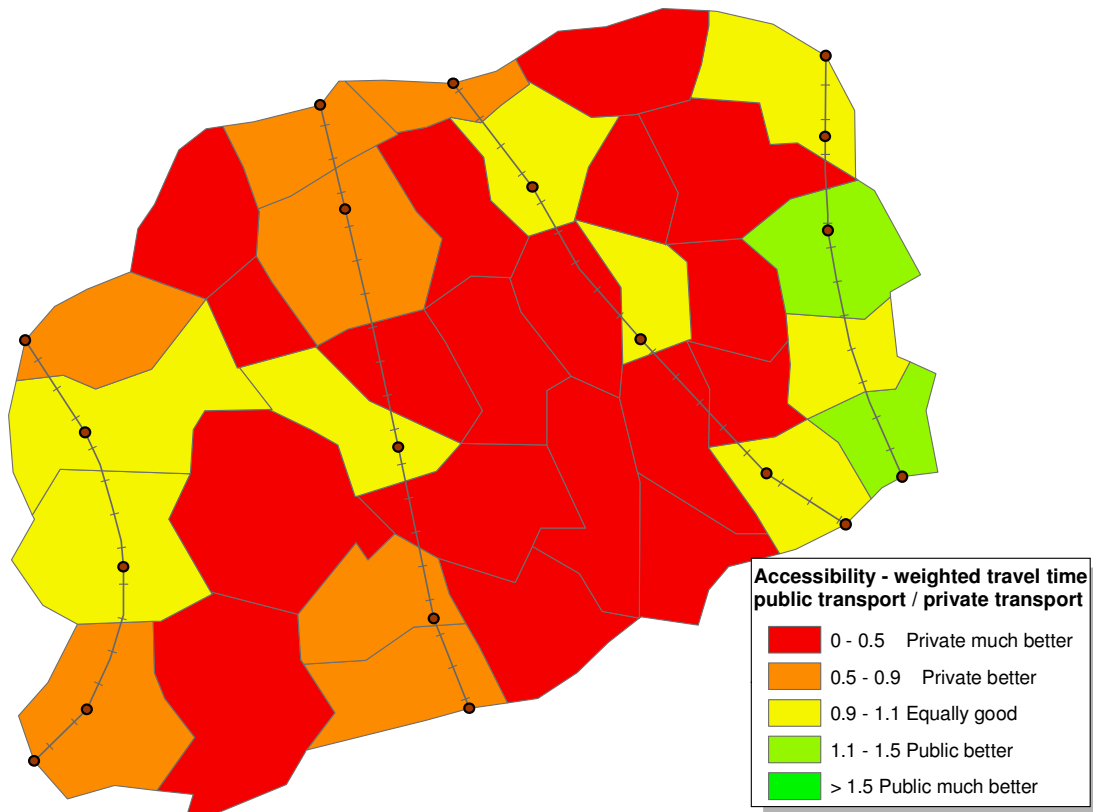


Figure 2.2 – The public transport share of traffic between municipalities (trip matrix data)

Figure 2.3 illustrates how good the travel time for public transport to all zones (accessibility) is compared to private traffic.



**Figure 2.3 – Travel time comparison between public and private transport to all zones
(trip matrix and cost matrix data)**

By comparing the public transport share (figure 2.1) and the travel time between car and public transport (figure 2.2) it is often seen that areas/zones with good/fast public transport have a higher market share for public transport. However, some zones may be different. Here it may be relevant to examine why the zones have more/less passengers than expected – e.g. due to very low/high income, difficult public transport services, and education facilities.

Generally, maps of regional accessibility and mobility should not be over interpreted since minor inexplicable tendencies are often seen. Only the superior implications should be addressed.

2.2 Station Vicinity

The important issue in the planning process of new public transport infrastructure is not the station vicinity areas but the non-station vicinity areas. The non-station vicinity areas are areas where the level of high quality public transport service is low. Because of that, these areas may have a potential for a new high quality public transport service. This potential is very much dependent on how built up the areas are (to which degree the station vicinity policy has been complied with).

Introducing a new high quality public transport service in non-station vicinity areas means that these areas can become station vicinity areas¹. This can result in a transformation of the areas. For instance providing more transport intensive land use and general urban condensation. Also areas that are not build up can be used as development areas and thereby support at high quality public transport service in the long term.

Maps in GIS are a clear and easy way to identify and make superior assessments of non-station vicinity areas. The station vicinity areas are identified by making buffers around the existing railway stations. This will visualize the coverage of high quality public transport in the area of interest (see figure 2.4). Size of the buffer depends on the analyses, however, in the Danish station vicinity policy a buffer radius of 1000 meter is used to define station vicinity.

¹ It is not certain that all types of high quality public transport will obtain station vicinity referring to the Danish station vicinity policy.

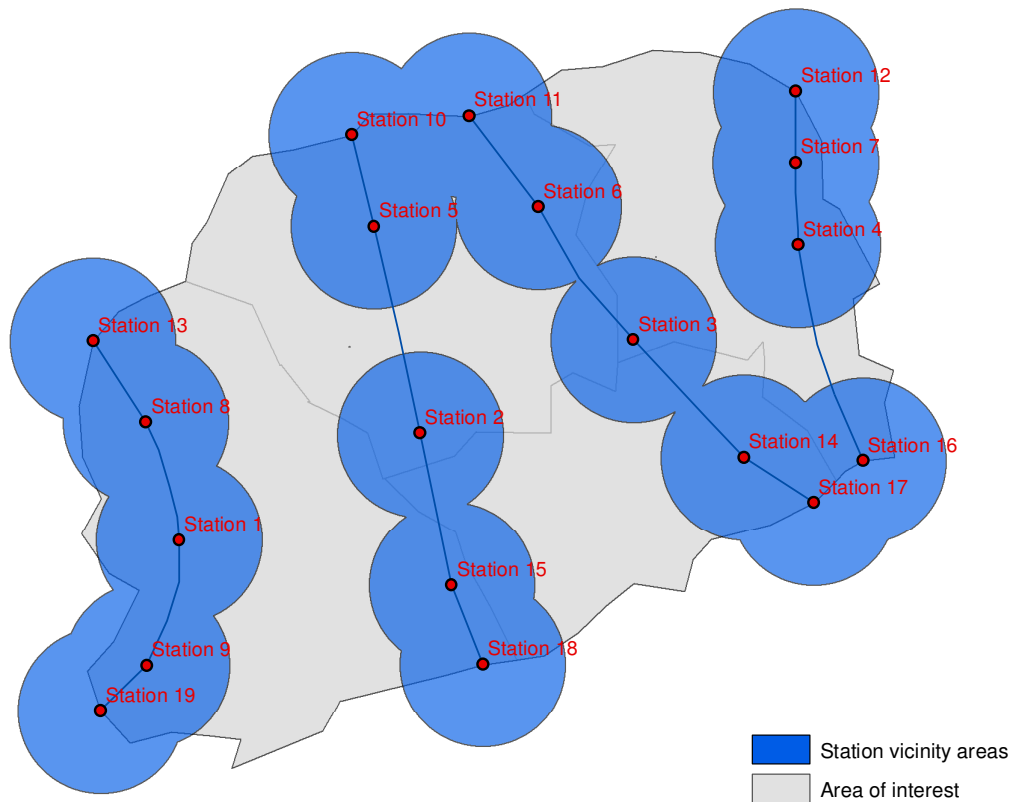


Figure 2.4 – Coverage of high quality public transport – Station vicinity (1000 m)

When the station vicinity areas are determined underlying maps can be implemented in the analyses. These maps should contain information that somehow indicates travel demand. This could be information such as:

- Land use
- Population (per area unit)
- Workplaces (per area unit)
- Travel potential² (per area unit)
- Buildings
- Car ownership
- Income
- Demography

² Travel potential is specified as $\text{Population} + 1.75 \times \text{Workplaces}$ (“Catchment area and transport modeling”)

The information about travel demand gives an indication whether the non-station vicinity areas are already receptive to high class public transport service.

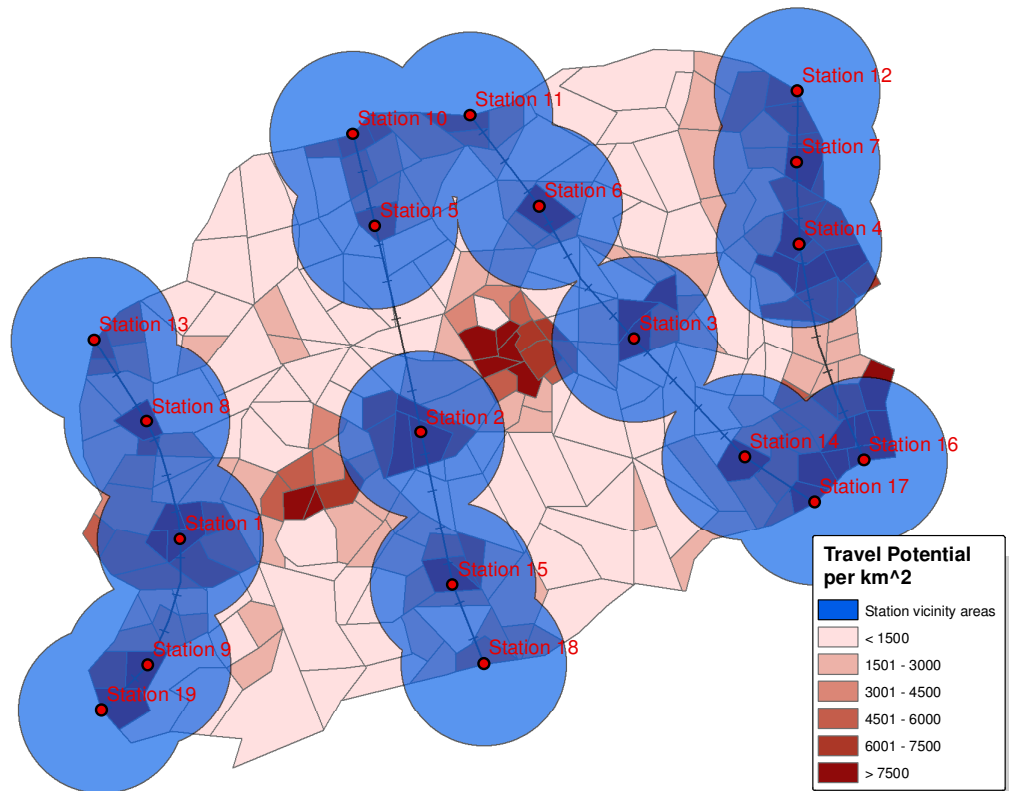


Figure 2.5 – Coverage of high quality public transport - Station vicinity (1000 m) with underlying information of travel potential

The investigations of station vicinity and travel demand can be done on large areas e.g. the Greater Copenhagen area. However, it is often useful with special attention on focus areas e.g. the investigated corridor(s).

2.3 Corridor definition

The superior corridor for the new public transport line should be decided on at this stage but the boundaries of the corridor are not determined yet. The investigations of regional accessibility and mobility as well as station vicinity should provide decision support to fine tune the definition of the corridor. However, deciding the exact boundaries of the corridor is also under influence from the existing geography. For

instance natural barriers like canals, lakes, hills etc. and man-made barriers like preserved areas, motorways and rail tracks etc. can be difficult to cross (see figure 2.6 for example).

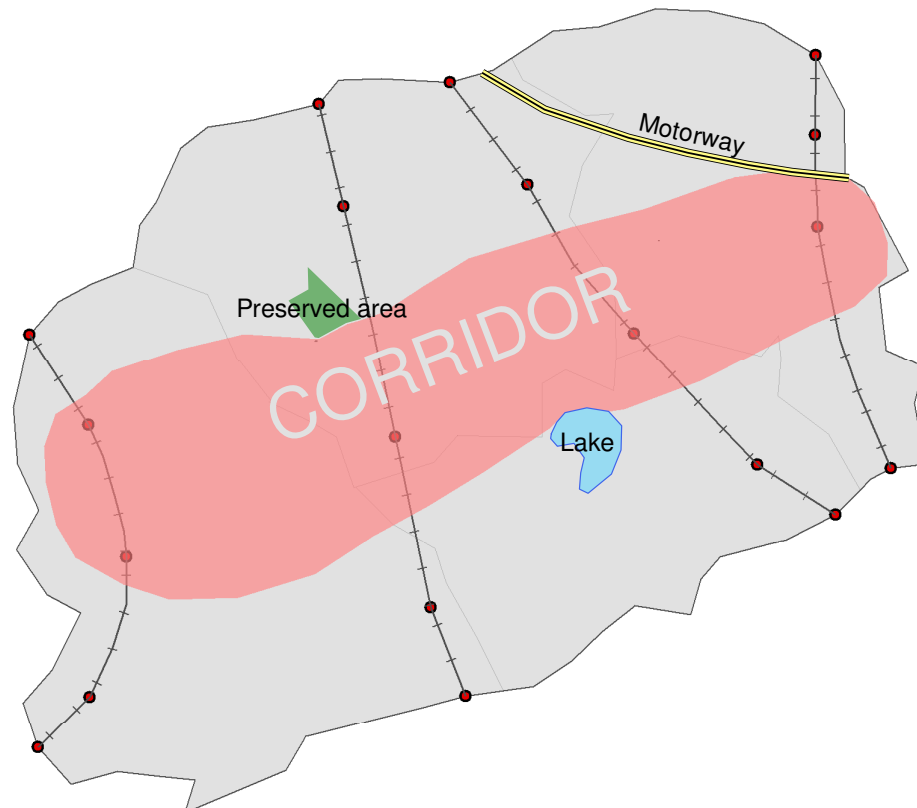


Figure 2.6 – The corridor can be restricted by existing natural and man made barriers

To support the definition of the corridor maps of travel demand and/or accessibility/mobility including the corridor can be useful. This can show whether the chosen corridor covers the areas that the preliminary investigations pointed out as in lack of (high quality) public transport service and where an upgrade of the service is desirable (see figure 2.7 for example).

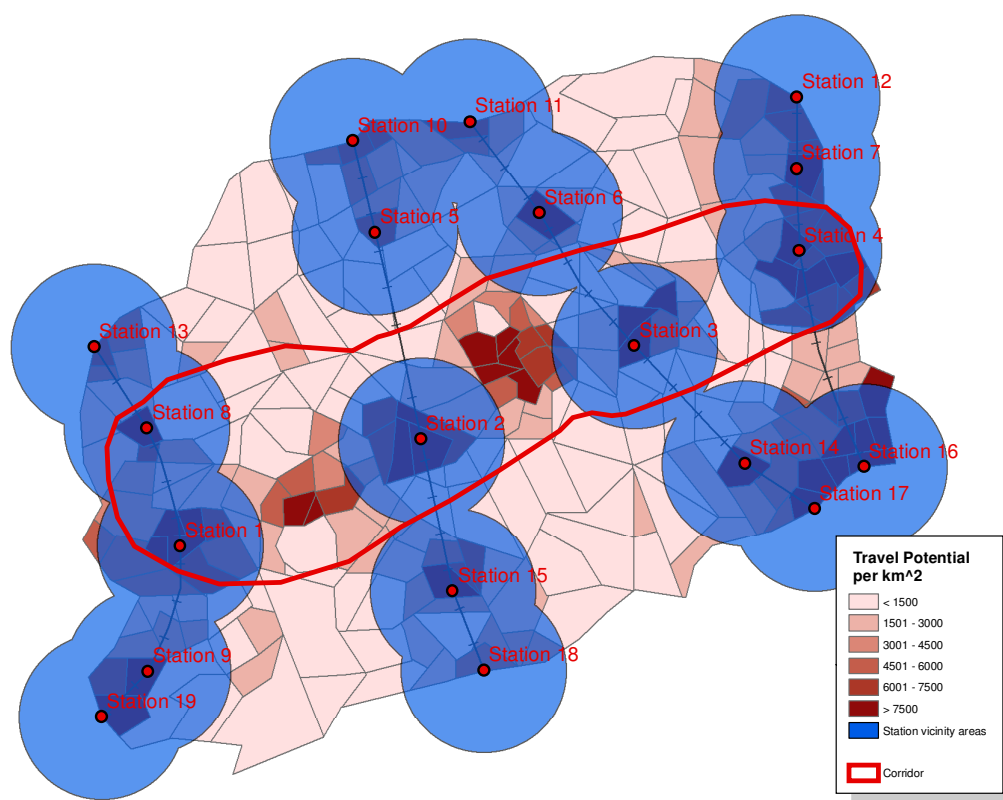


Figure 2.7 – Non station vicinity and travel potential within the corridor

The chosen corridor will form a geographical base for the alignment placing.

3 Alignment

Alignment planning is the planning of the physical placement of a public transport line. The term is primarily used to define railway (and light rail) route. There are a lot of factors that influence the alignment placing and therefore must be incorporated in the planning process.

3.1 Planning parameters

When planning the alignment of a new public transport line there are some important planning criteria that should be included. They are listed in table 3.1 and described afterwards.

<ul style="list-style-type: none"> • Travel potential <ul style="list-style-type: none"> ○ Access/egress passengers in serviced areas ○ Optimization • Connections with other public transport <ul style="list-style-type: none"> ○ Transferring passengers ○ Optimization • Travel time <ul style="list-style-type: none"> ○ Improving existing service ○ Minimization • Construction cost <ul style="list-style-type: none"> ○ Length dependent, bridges, expropriation etc. ○ Minimization • Special location service <ul style="list-style-type: none"> ○ Universities, hospitals, stadiums etc. ○ Optimization • Availability of space (for ground level solutions) <ul style="list-style-type: none"> ○ Track placing and width of roads ○ Constraint

Table 3.1 – Planning criteria for alignment

The alignment placing process should accommodate all of these planning parameters at some level.

3.1.1 Travel potential

Travel potential is probably the most important parameter since it is a strong indicator for travel demand and is based on access/egress customers. This means

the passengers that the public transport line can service in the area it passes. It is beneficial with a map of travel potential as aid when placing alignments. It may also be relevant with travel potential graphs to support the alignment placing (introduction to travel potential graph in chapter 4, subsection 4.2 Positioning of stops).

3.1.2 Connections with other public transport

Is also a very important parameter since it is based on transferring passengers. A map of existing public transport stops and stations are beneficial in the process. Especially connection to high quality public transport like rail is very important. In the planning process this can be taken into account by using fixed stop areas where transfers are possible (more of this in subsection 3.2 Planning approach).

3.1.3 Travel time

The travel time is also an important parameter. If the alignment becomes too tortuous and too long the travel time will be too high. This may result in losing the regional effect of the new line (because of longer travel time from end to end) and it may also result in fewer passengers. It is important that the new line will have a better travel time than the existing public transport services of the corridor.

3.1.4 Construction cost

A more tortuous and long alignment will result in higher construction cost and – when the travel time also increases – consequently higher operating cost. Furthermore, the alignment should be planned so expensive solutions like bridges; tunnels and expropriation are avoided if possible.

3.1.5 Special location service

It could be a specific desire and at least a good idea to service some big institutions like universities, hospitals etc. where the travel demand is high. Some of it is already included in the travel potential but the travel potential does not take the impact of pupils and students into account. Furthermore, it does not take into account that schools and universities attract more public transport customers due to the lower car ownership of these users. Another issue is that the travel potential does not take attractions like stadiums, beaches etc. into account because of their irregular impact. But they can be special locations desired to service. A map of such special location can be a good idea to have in the alignment placing process (see figure 3.7).

3.1.6 Availability of space

Availability of space is only an issue for ground level (light rail) or – to a lesser extent – elevated solutions. The availability of space is correlated to the width of the roads and the track placing. There are a number of different track placing types for light rail systems and they are usually conditional on the space available and the general conditions of the corridor (see table 3.2).

- **In streets with mixed traffic**
 - Traditional tram driving using the same lanes as car traffic
- **Reserved lanes**
 - Side or centre placed lanes restricted for light rail driving
 - Can be separated from car lanes by curb or bumps or no separation (like bus lanes)
- **Segregated tracks**
 - Closed alignment for light rail with no other traffic to obstruct (like traditional rail)

Table 3.2 – Superior track placing types for light rail systems

The availability of space and track placing also have an influence on the achievable speed for the system. Reserved lanes and segregated tracks ensure high speed whereas mixed traffic driving result in low speeds. A rule-of-thumb is that modern light rail system must not drive more than 5-10 % of the alignment in mixed traffic otherwise they become more like traditional trams and less attractive.

In figure 3.1-3.4 thematic cross sections for the most common used track placing types for light rail are illustrated. Mix of the different types can occur and boundaries are fluid e.g. a reserved lane with very high curb has similar characteristics as segregated tracks.

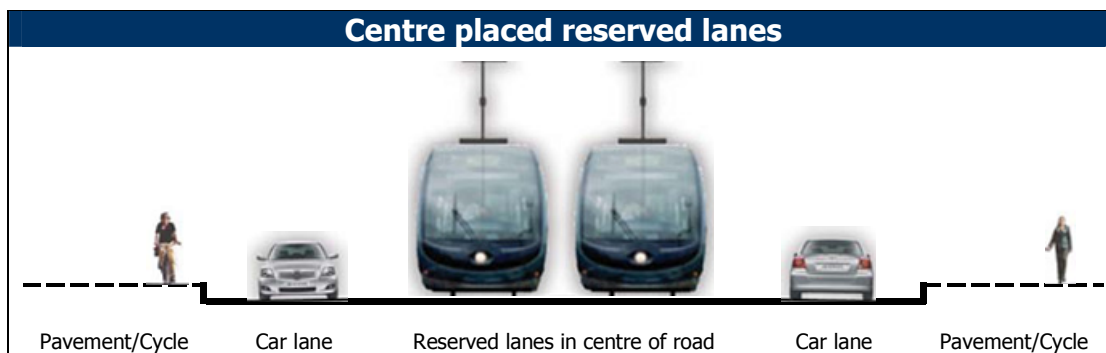


Figure 3.1 – Track placing for light rail – Centre placed reserved lanes

Centre placed reserved lanes as in figure 3.1 is the most common used track placing type in urban environments. Often the lanes are separated by a curb or bumps to prevent car traffic on the tracks but still easy to cross for vulnerable road users. Light rail speeds can be up to 20% higher than the allowed speed for the cars but it depends on the conditions and enclosure of the tracks.

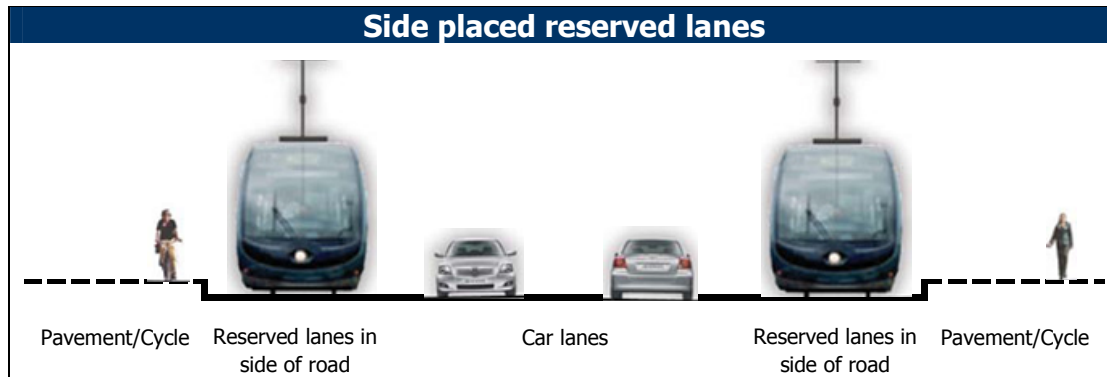


Figure 3.2 – Track placing for light rail– Side placed reserved lanes

Side placed reserved lanes as in figure 3.2 have some of the same characteristics as centre placed reserved lanes regarding speed and crossing of tracks. However, it is not used very often because there are some inconveniences compared to centre placed lanes. First of all it is more expensive to construct in each side of a road (double up on work, power poles, platform etc.). Second it tends to conflict more with the vulnerable road users since they are very close physically. Third it often conflicts with the accessibility to the road and obstructing the flows to/from secondary feeder roads. Consequently, side placed reserved lanes are usually only used if the conditions requires it e.g. when having obstacles in the centre of the road.

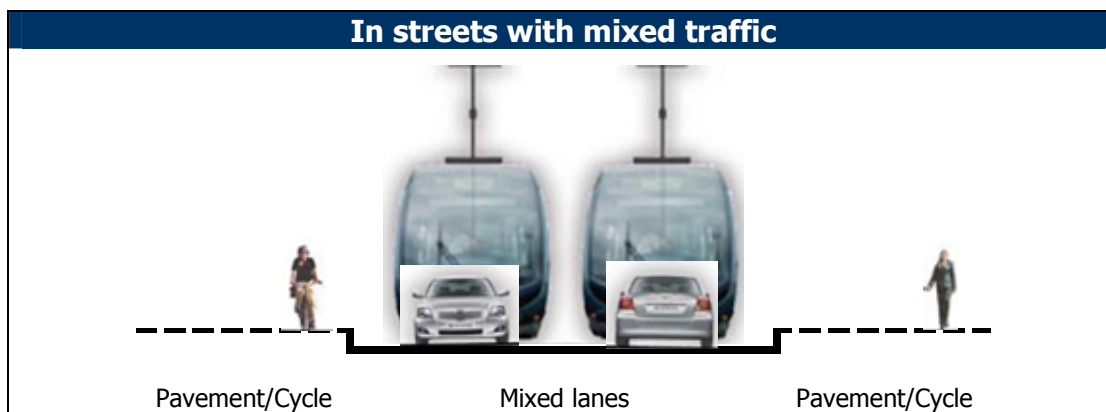


Figure 3.3 – Track placing for light rail– Mixed traffic driving

Mixed traffic driving (figure 3.3) where the light rail drives as traditional tram in the same lanes – and on a level playing field – as car traffic should generally be avoided (only 5-10 % as previous mentioned). This is because light rail speeds can not exceed the actual speed of the cars and it may be influenced by congestion. In some cases e.g. where roads are very narrow it can be the best solution but sometimes it can be an equally good solution to close the road for car traffic (or at least through-traffic).

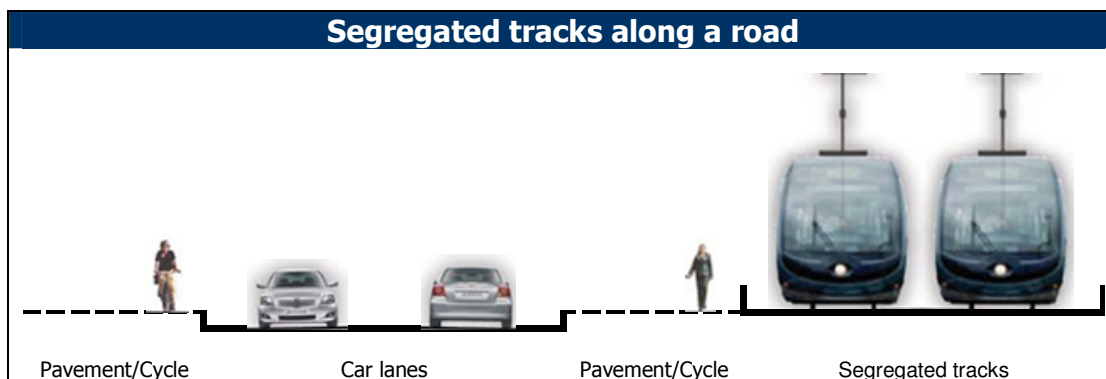


Figure 3.4 – Track placing for light rail– Segregated tracks

Segregated tracks is the best way to ensure high travel speeds since it keeps all other traffic away from the tracks. If the tracks are fenced in and there are no intersections light rail speeds can reach over 100 km/h. The segregated tracks can be placed along a road (as in figure 3.4) if there is enough space but it can also run independently of roads like traditional rail.

3.2 Planning approach

The first step can be to predefine the end stops of the new line. There can be more than one end stop in each end if the alignment branches because there is more than one obvious location to end the line. End stops should – at least in one end – preferable be connected to a larger terminal with connection to other high quality public transport in order to ensure good network effects.

Next step can be to predefine fixed stop areas in the corridor. Fixed stops are usually connections to other high quality public transport systems where the new line needs to stop to ensure transfers. However, fixed stops are a question of definitions and depend on the conditions of the corridor.

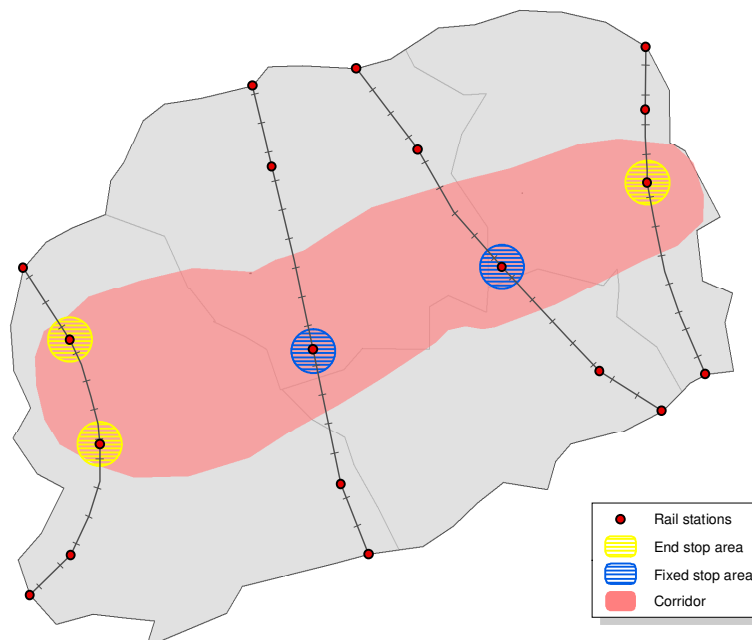


Figure 3.5 – Predefined end stops and fixed stops for the new line

When potential end stops and fixed stops are decided on the planning of the alignment between these predefined stops can begin. The planning must be conducted following the planning criteria listed in table 3.1. It can also be a good idea to glance at the existing public transport line(s) in the corridor for inspiration.

It is good practice to show details of the alignment planning. This can be done by showing map zooms with different substantiated information of all alignment

stretches. An example is shown in figure 3.6 where the detailed course of alignment alternatives is visualized. Such zooms should be done for all the alignment.

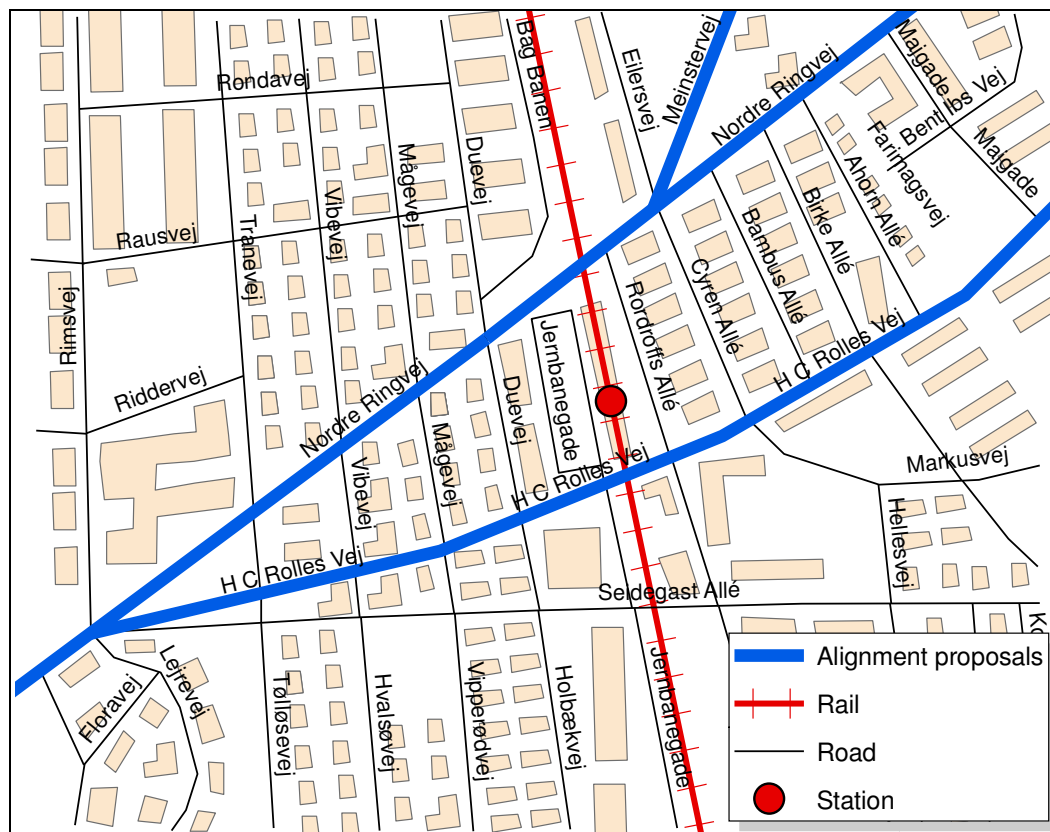


Figure 3.6 – Detailed course of alignment alternatives

Another example is figure 3.7 where special locations that may be relevant to service by public transport are shown. Such maps should be presented for all of the alignment.

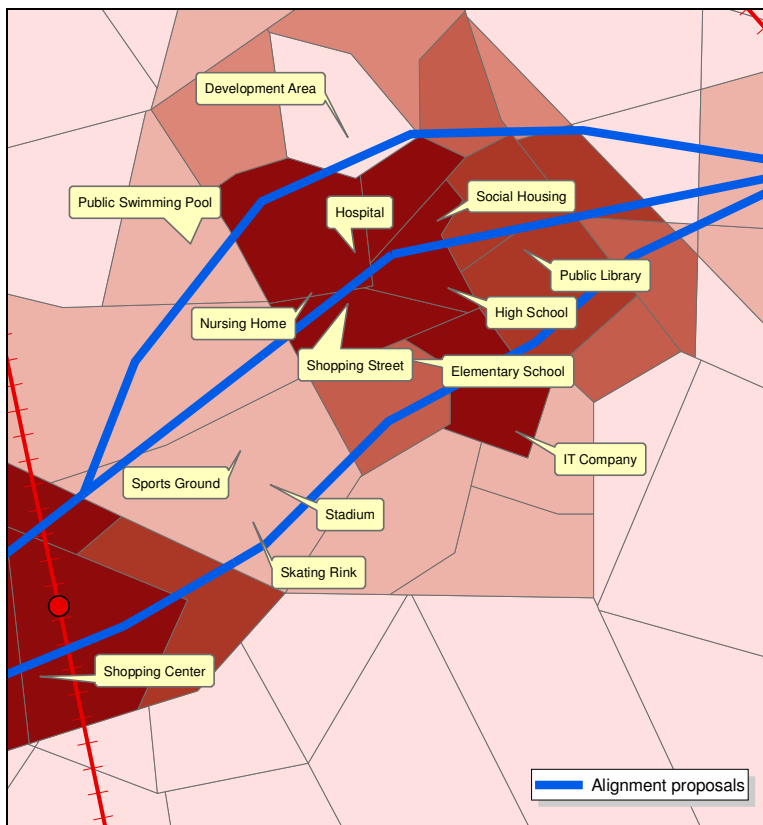


Figure 3.7
Special locations to service
with alignment alternatives

3.2.1 Alternatives

The alignment planning will (especially for ground level solutions) often result in multiple possibilities for the positioning of the alignment. These can offhand be difficult to judge the best one from and they are, therefore, worked with further on in the analysis referred to as alignment alternatives or proposals (e.g. see figure 3.7). Alignment alternatives appear because there may be a wish to service different locations, terminals or roads within the corridor. Therefore, the conditions of the corridor determine how many alignment proposals there will be. Also a wide corridor often results in more alternatives (see figure 3.8).

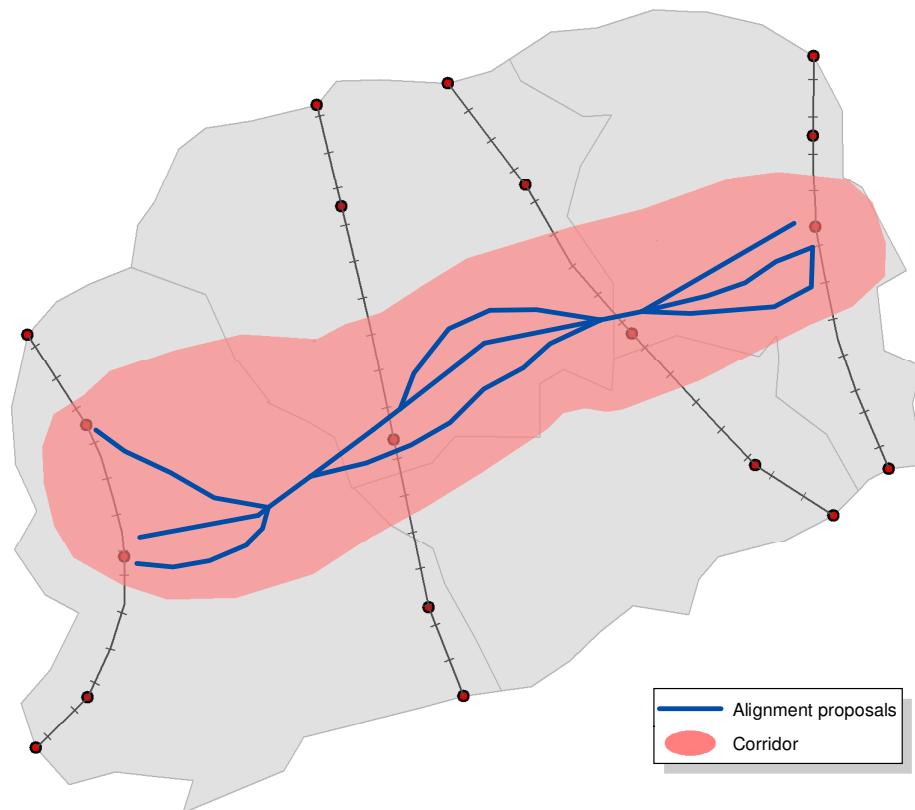


Figure 3.8 – Multiple alignment possibilities (alternatives) within the corridor

It is also good practice to show a map of the track placing for the alignment alternatives as seen in figure 3.9.

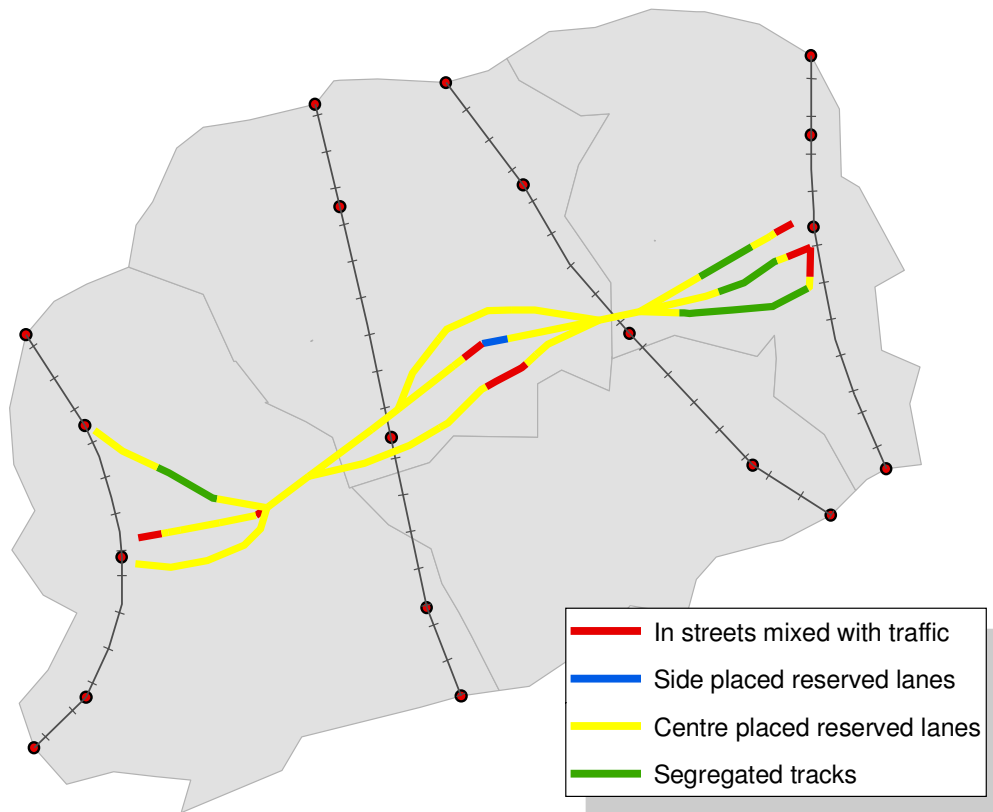


Figure 3.9 – Track placing for all alignment alternatives

It can also be relevant to show thematic cross sections of the track placing types used for the new line (see figure 3.1-3.4 for examples).

3.2.2 Assessment of alignment alternatives

It can be difficult to know which alignment proposals that constitutes the best solution for the new line. Traffic modeling of all alternatives would be the optimal approach but this is also a very time consuming process. The second best solution is to locate stops on all alignment proposals and implement them all in the catchment area analysis. This is also a little time consuming but not as much as traffic modeling. However, there are methods to deselect the poorest alternatives before the stop positioning and catchment area analysis.

One simple approach that can be used to evaluate alignments is line potential. Line potential is simply the travel potential within a specific distance of the alignment. The

distance should be something that corresponds to willingness to walk distance and the line potential is calculated from line buffers and overlay analysis with travel potential data (more about this in chapter 4).

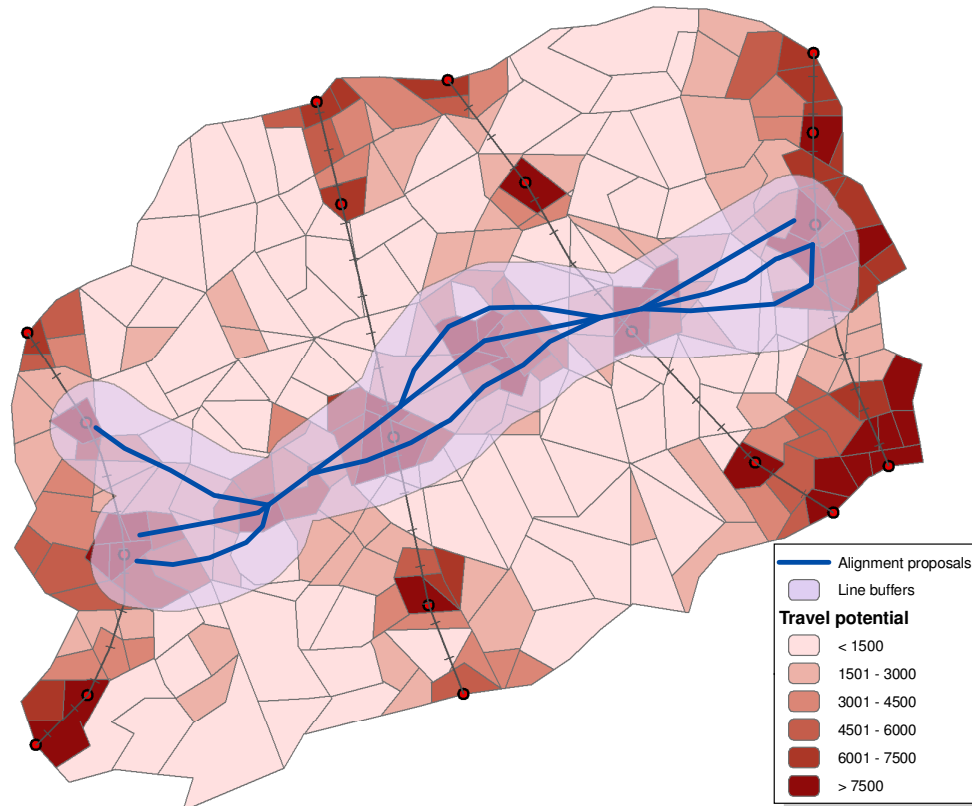


Figure 3.10 – Line buffers of all alignment alternatives intersected with underlying travel potential data

When working with many alignment alternatives it can be complicated to investigate line potential from end to end since it will produce a lot of different alignment combinations. If there are some common stretches for all alignment alternatives it can be beneficial to divide the alignment into sections as seen on figure 3.11.

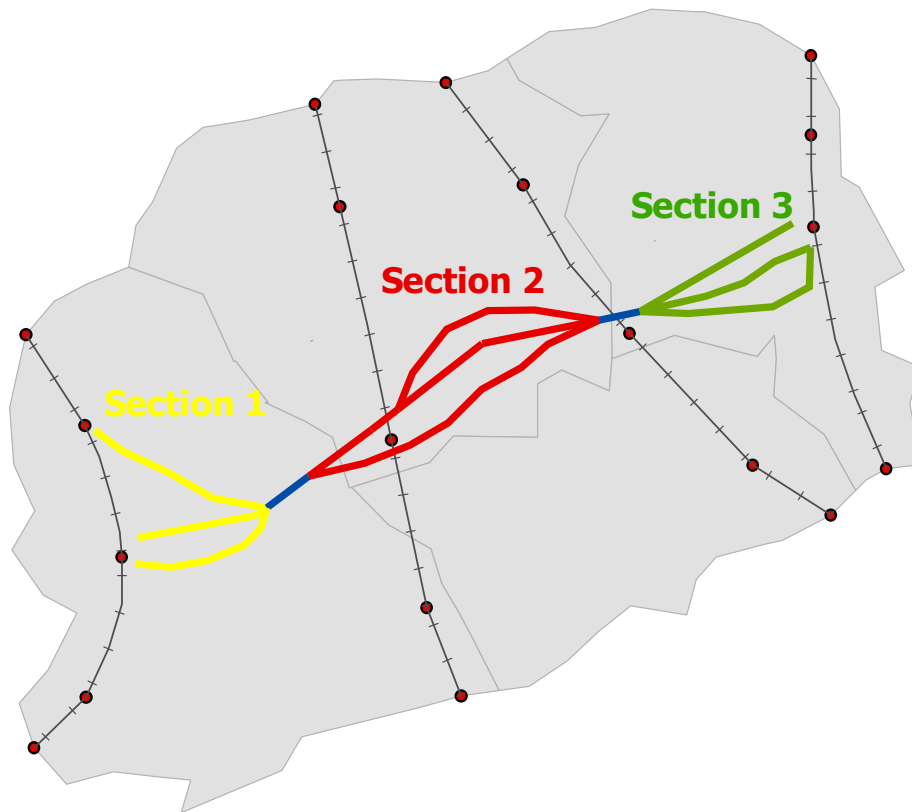


Figure 3.11 – Alignment proposals divided into sections

By dividing the alignment alternatives into sections each section can be investigated separately lowering the combinations of alternatives considerably. It is good practice to give a clear and cohesive presentation of alternatives and results from the line potential calculation – this includes both description and figures/tables (see table 3.3).

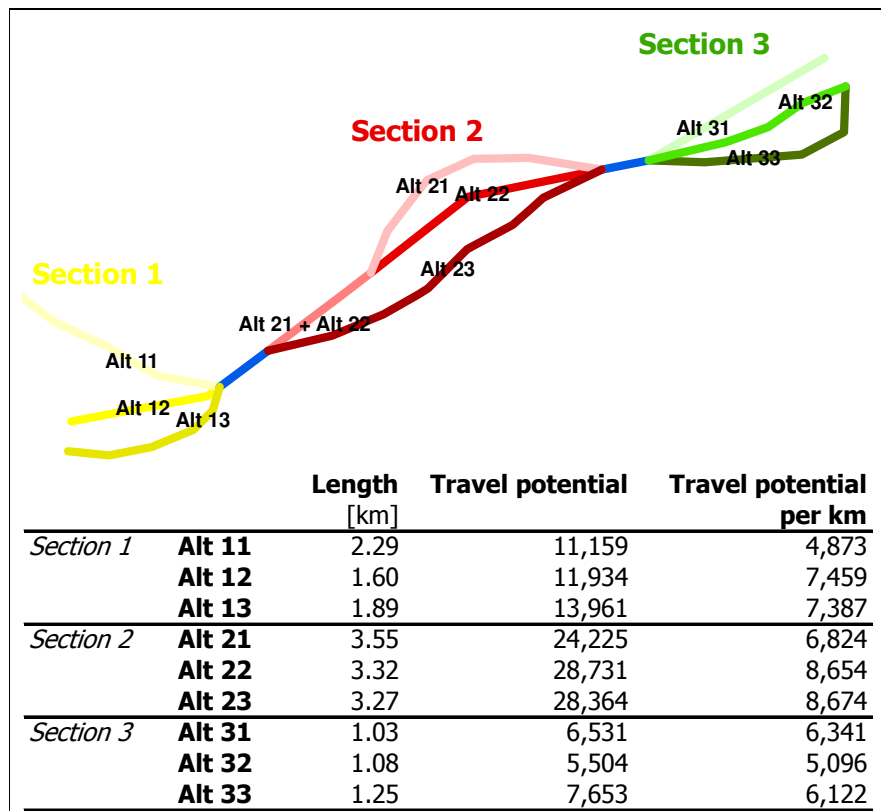


Table 3.3 – Line potential for all alignment alternatives

Line potential is not a fully realistic approach since a public transport line only can be accessed in defined points (stops) and it is not possible to service all travel potential along a line. But if there are many alignment alternatives in play the line potential approach can serve as decision support to deselect the least suited for further analysis. However, other arguments taken from the planning criteria (table 3.1) must also carry weight in the deselecting process.



Figure 3.12 – Alignment alternatives after deselecting the least suited

Those alignment alternatives that appear reasonable equal both from the planning criteria and line potential can not be decided on in the alignment deselecting process. They have to undergo further analysis and will therefore get appointed stops and be included in the catchment area analysis.

4 Stops

Stops are the passengers access to public transport and the planning of them are of high importance. When planning a new line initial stops should be positioned along the alignment. In advance it may be difficult to know where the best locations for stops are and therefore analysis of catchment areas can be a strong decision tool in the positioning process and in selecting the best stop locations.

4.1 Definitions

Before any analysis can be performed there are a couple of important aspects that must be described and defined.

4.1.1 Accessibility to public transport

In the planning of public transport accessibility is very important. Accessibility can be improved by upgrading streets and paths surrounding stops or stations e.g. by pedestrian bridges etc. Also the location, access and number of entrances to the platforms are important (more of this in subsection 4.3.1 Accessibility to stations).

4.1.2 Catchment area

Catchment area of a stop is the vicinity of the stop or the area that encircles the stop. It is the area where most of the non-transferring passengers come from and thereby the customer base for public transport. In most catchment area analysis the catchment area is circular as seen in figure 4.1.



Figure 4.1
Circular catchment area

Another and more refined approach is the Service Area Approach where the catchment area is defined from impedance in a network search (see figure 4.2). The Service Area Approach has more realistic catchment areas but it also demands a high level of detail especially from the network that e.g. must include pathways. ("GIS-based approaches to catchment area analysis of mass transit").

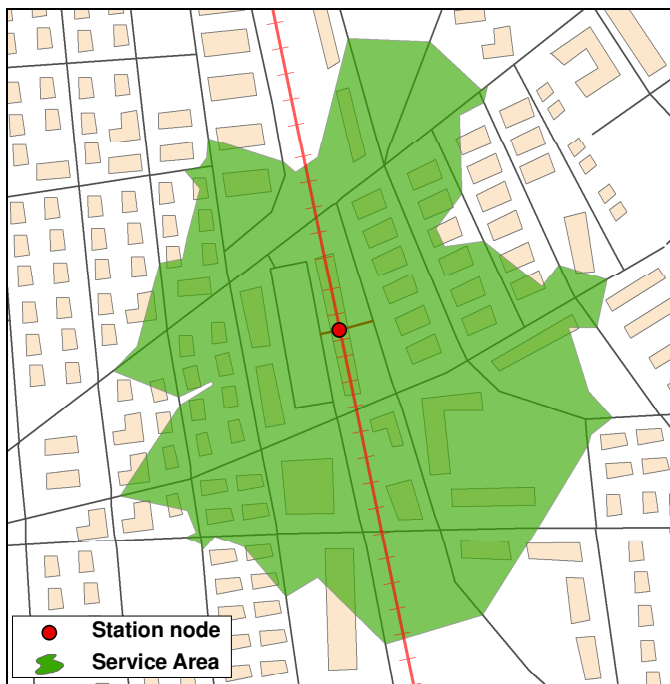


Figure 4.2
Service Area – Catchment area
based on network search

For simplicity, all catchment areas will be circular in the following.

4.1.3 Overlay analysis

Overlay analysis is the geographical approach used to conduct catchment area analysis. It consists of two geoprocessing steps: creating catchment area buffers and intersecting them with underlying travel demand data. In that way information of travel demand can be attached to the geographical catchment area buffer (see figure 4.3).

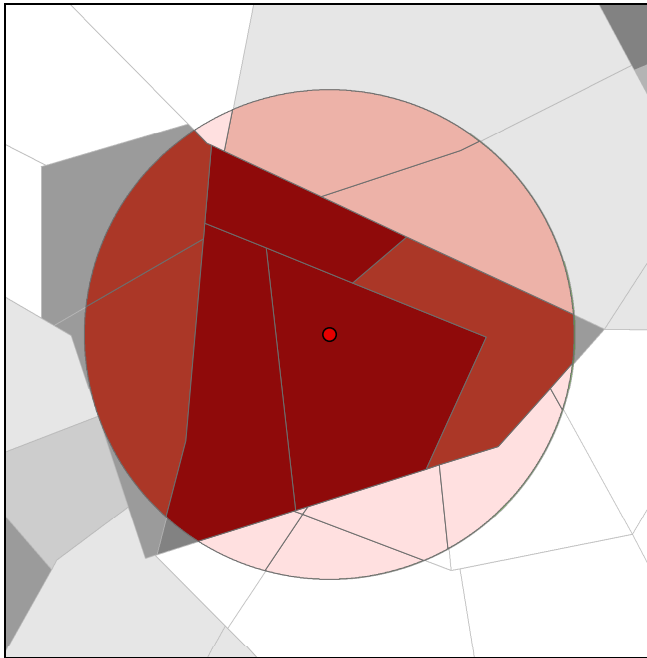


Figure 4.3
Overlay analysis – Catchment area
buffer intersected with underlying
travel demand data

4.2 Positioning of stops

Positioning of stops on a brand new alignment requires some of the same approaches as planning the alignment itself. Therefore, the planning criteria from table 3.1 should be used in the process. However, in the stop positioning it is the number of stops that affects the travel time and construction cost. Good practice is to scrutinize the stop positioning as thorough as the alignment planning and include relevant maps and zooms.

Travel potential is perhaps the most important planning parameter and in order to use that in the stop positioning process a travel potential graph can be helpful. A travel potential graph appears by making a catchment area for every X meter (e.g. every 50 m or every 100 m) and then making an overlay analysis of each catchment area buffer with underlying information of travel potential (see figure 4.4).

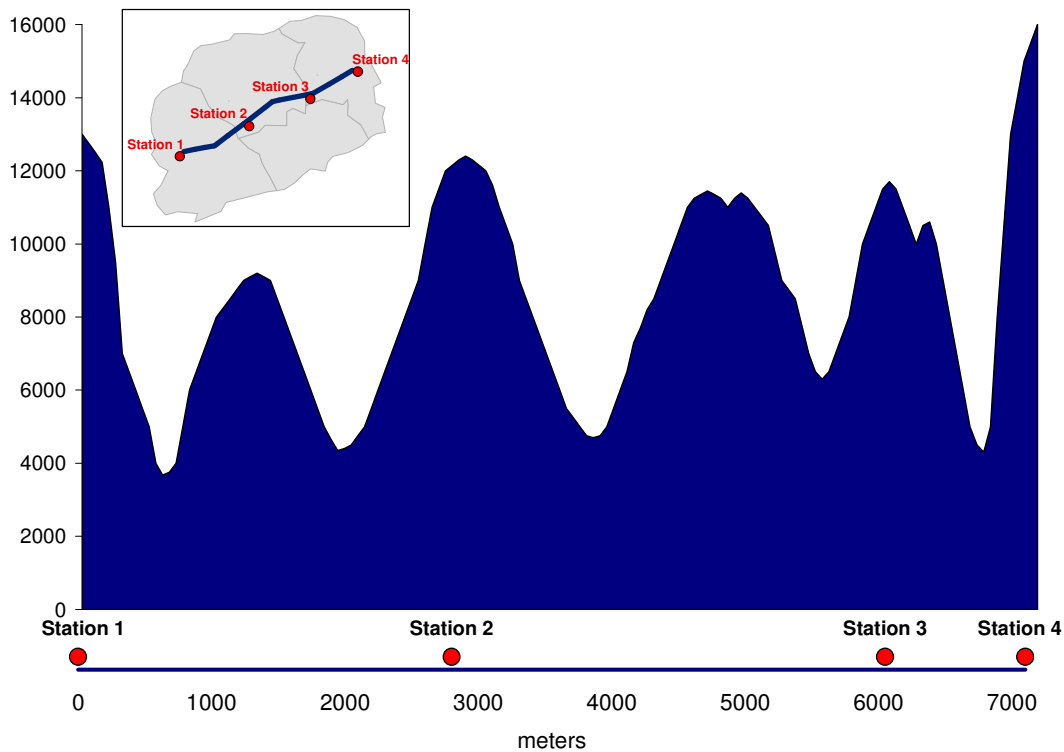


Figure 4.4 – Travel potential graph for one alignment alternative combination (including positioning of existing stations)

The travel potential can give an indication of the customer base along the alignment and where to place stops. But keep in mind that connection to high quality public transport is equally important and it is very important to get a close connection between platforms to minimize transfer distances.

Another issue in the stop positioning is the number of stops. The number of stops can be difficult to determine mainly because of its impact on travel time. It is a balance between servicing along the line and fast service from end to end. It depends on the type and quality of the public transport and of the areas that it service. For instance heavy rail should have lesser stops than light rail because of longer acceleration/deceleration times. High density urban areas with large travel potential call for more service (and thereby more stops) than rural areas where speed is essential. In addition to the travel time, the number of stops affects the construction cost but while ground-level stops – like light rail stops – are relative inexpensive, underground stations influence heavily on the construction cost.

When determining number of stops at a new line good practice can be to glance at other public transport lines of similar type and functions. If the corridor has an existing public transport line (e.g. a bus line) the stops of that line and their passenger volumes can also be studied for aid.

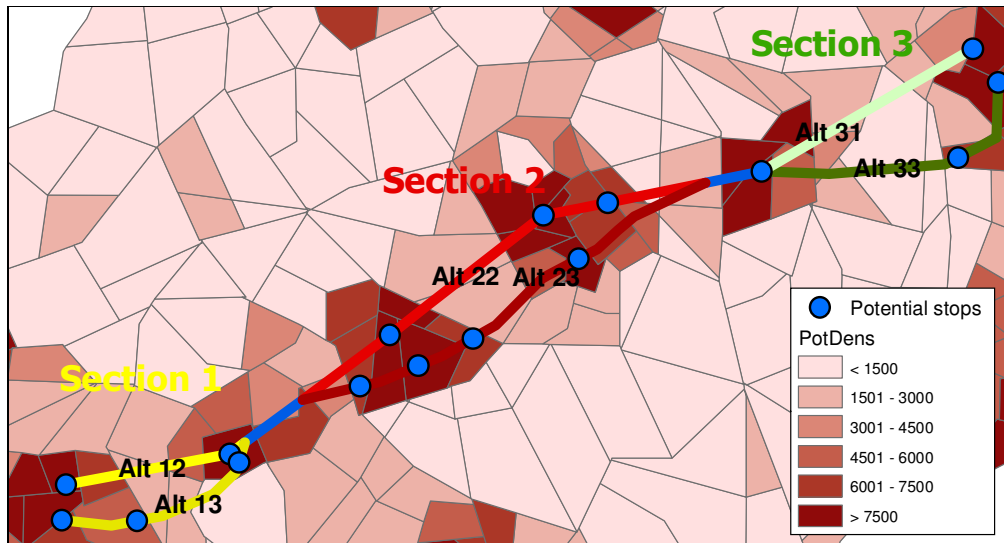


Figure 4.5 – Positioning of potential stops for remaining alignment alternatives

Multiple stop pattern solutions can be incorporated for each alignment alternative. That means making stop pattern alternatives by changing number of stops and/or positioning. Stop pattern alternatives should be listed in a clear way preferably with a reference to a map as seen in table 4.1.

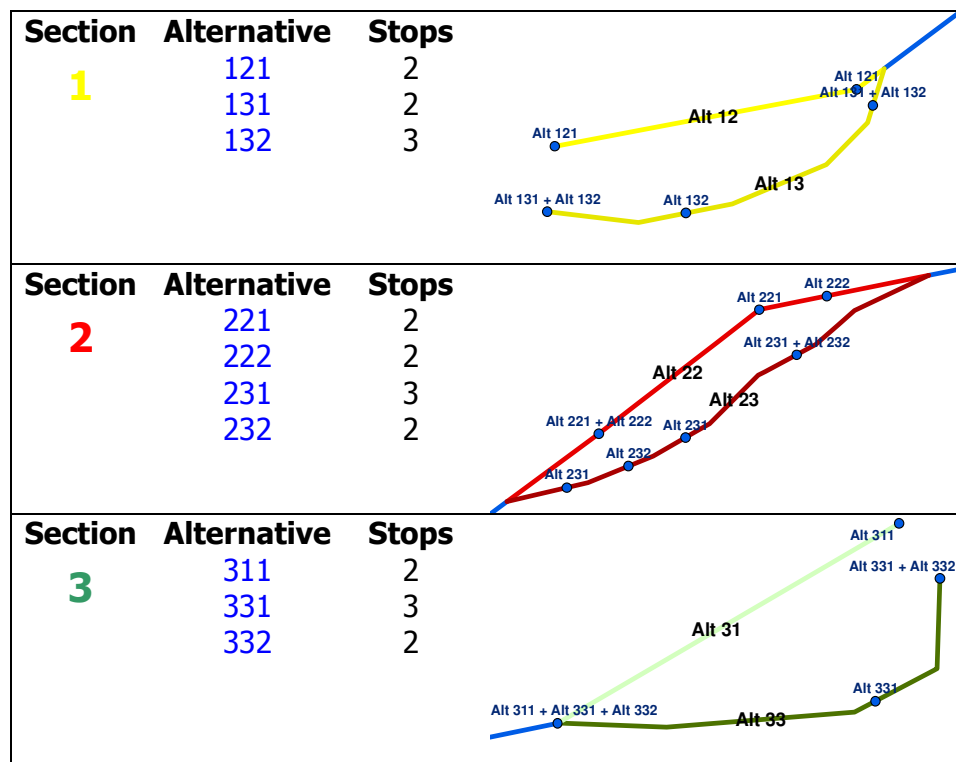


Table 4.1 – Stop pattern alternatives

When all remaining alignment alternatives have appointed stops they are ready to undergo analyses to find out which combination is best.

4.3 Catchment area analysis

To determine the final alignment and stop pattern between multiple alternatives decision support like catchment area analysis can be useful. Catchment area analyses are based on overlay analyses in GIS where the catchment area buffers are intersected with underlying information of travel potential (same principle as for the travel potential graph in figure 4.4). Using catchment area analyses for investigations of stop pattern alternatives should be a little more advanced than for the superior travel potential graph. It should include more aspects in order to get more detailed results.

Before conducting catchment area analysis there are some definitions that should be addressed. These definitions are going to be used in the analysis and must be decided on in advance.

4.3.1 Accessibility to stations

The accessibility to stations should be taken into account by making catchment area around entrances instead of only to the center of the station (the station node). This can result in an increase of the catchment area which is considered to be more realistic (see figure 4.6).

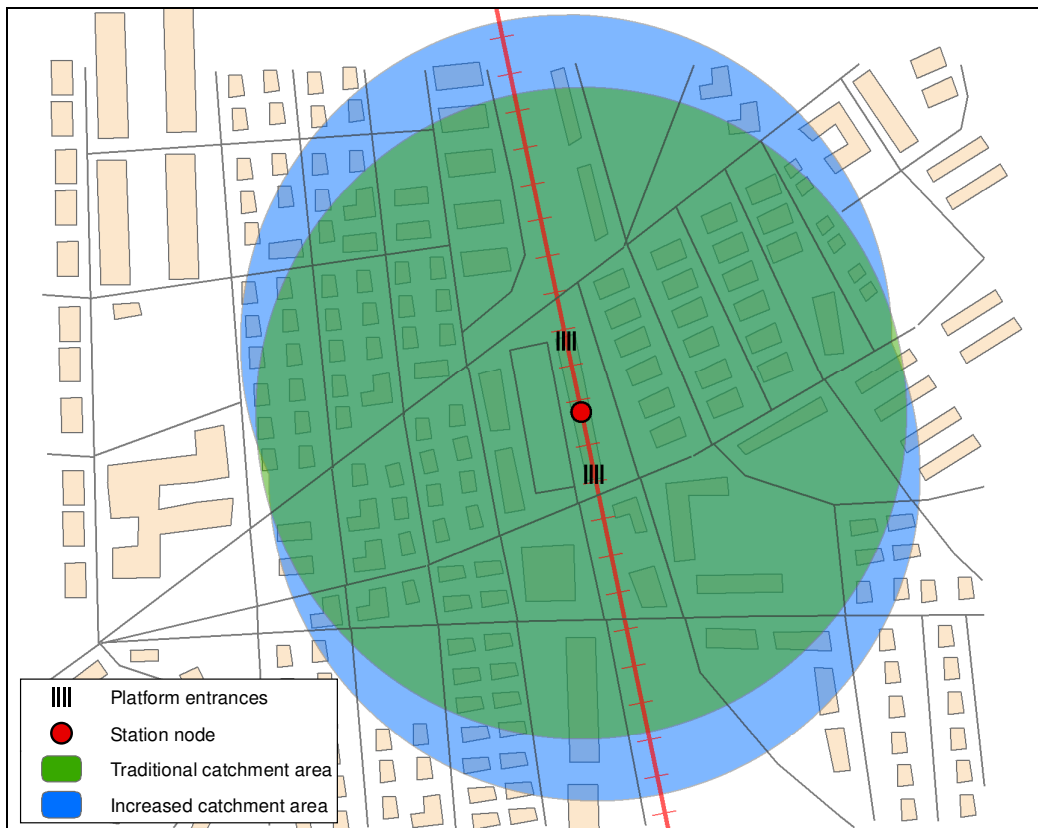


Figure 4.6 – Increased catchment area due to implementation of platform entrances

4.3.2 Catchment area size and division

The size of the catchment area depends on the willingness to walk. This willingness is mostly affected by the quality of the public transport but also by factors such as total length of the journey and number of transfers, land use and walking environment.

The catchment area can be divided into multiple subareas (rings) with different market shares applied as function of the distance from the station. But often the analysis is simplified by only dividing catchment areas into two; a primary and a secondary catchment area. The primary catchment area can then be defined from willingness to walk criteria and the secondary from willingness to bike or as a passenger percentage. However, the secondary catchment area is often determined as seen in figure 4.7.

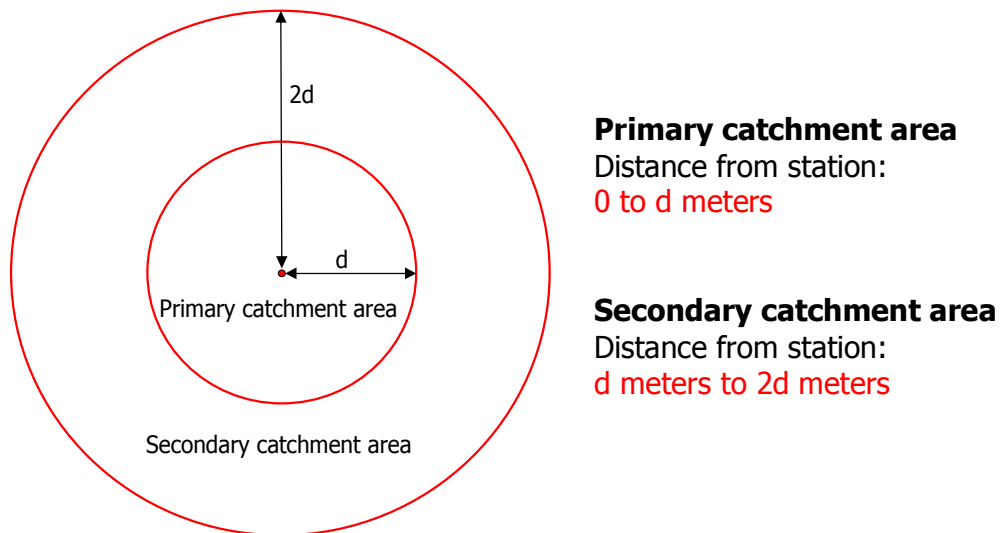


Figure 4.7 – Principle of common used division of catchment areas into primary and secondary

A general guideline for catchment area sizes dependencies of the quality of public transport can be seen in table 4.2. The figures are only guesstimates based on tendencies from different studies (e.g. "Feeder geography at bus stops" and "Walking distances to and from light-rail transit stations") and cannot be used uncritical and without argumentation or references.

	Urban rail/Metro Primary: 0-500 m Secondary: 500-1000 m
	Local trains Primary: 0-400 m Secondary: 400-800 m
	Light rail Primary: 0-350 m Secondary: 350-700 m
	Bus Primary: 0-250 m Secondary: 250-500 m

Table 4.2 – Inferred tendencies of catchment area sizes depending on the quality of transport

There must be some kind of mutual weighing between the primary and the secondary catchment area in the overlay analysis. This is to ensure that the primary catchment area utilize a higher share of the travel potential than the secondary. Ideally, the weighing is based on market shares as function of the distance from the station but only two weights can be applied when having a primary and secondary catchment area (but they can still be based on market shares).

Different studies of market shares of urban rail stations (e.g. "7 Planning themes for S-trains" and "Accessibility analyses")³ makes it reasonable to asses that the market

³ Studies use different catchment area sizes than seen in table 4.2

share of the secondary catchment area is half of the market share in the primary catchment area. Therefore, one simple way to define the mutual weighing can be as in figure 4.8.

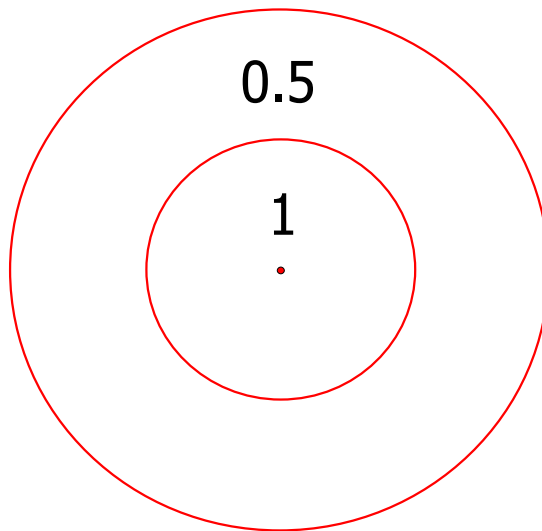


Figure 4.8
A simple way to apply weights to primary and secondary catchment areas (based on market share studies)

More detailed weighing and division of catchment area e.g. by applying multiple catchment area rings and multiple market shares and/or separating workplaces and population from the travel potential can be performed but is more resource demanding.

4.3.3 Overlapping catchment areas

With basis in the new line overlapping catchment areas with other public transport should be taken into account. If the quality of transport is regarded the same and the catchment areas thereby are of the same size (e.g. Urban Rail and Metro cf. table 4.2) they can be included in the analysis as one. Good practice is to include catchment areas of all rail lines but exclude catchment areas of bus lines.

Even though overlapping catchment areas from other lines will result in “stealing” of passengers from the new line an overlap should be regarded as positive since the general service of public transport in the overlapping area is higher than before. A simple way to apply this to overlaps – with the weights of primary and secondary catchment area as basis (figure 4.8) – can be seen in figure 4.9.

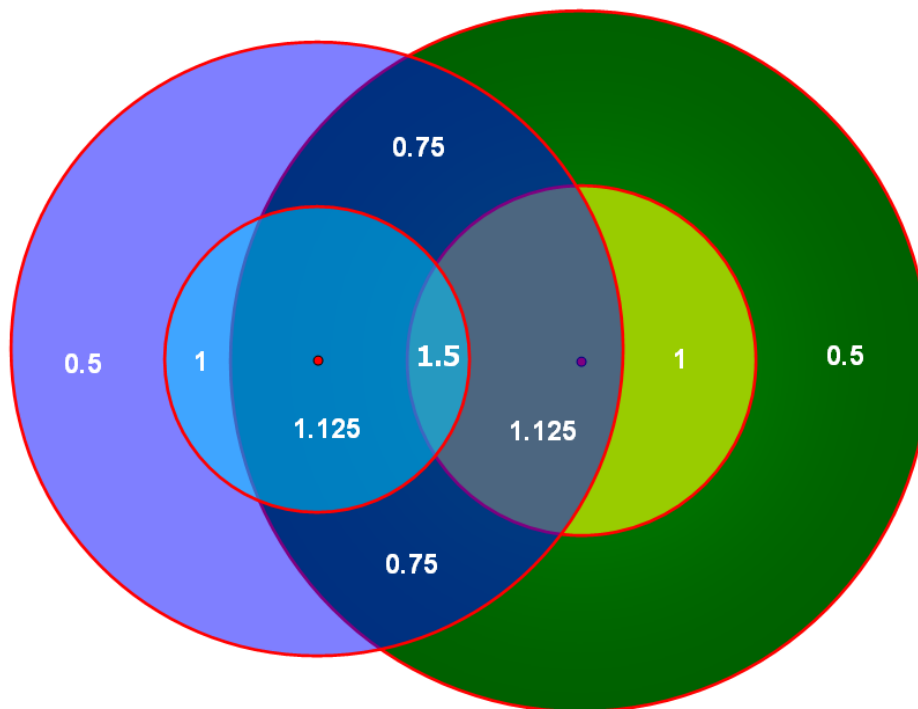


Figure 4.9 – A simple way to handle weights in overlaps

Weights are the same for all types of public transport since the quality issue is handled by different catchment area sizes (cf. table 4.2).

4.3.4 Analysis

In the catchment area analysis each alternative and each section must be calculated separately. A visual presentation of the catchment area analysis as in figure 4.10 can be good to illustrate the method but is not really relevant for the results.

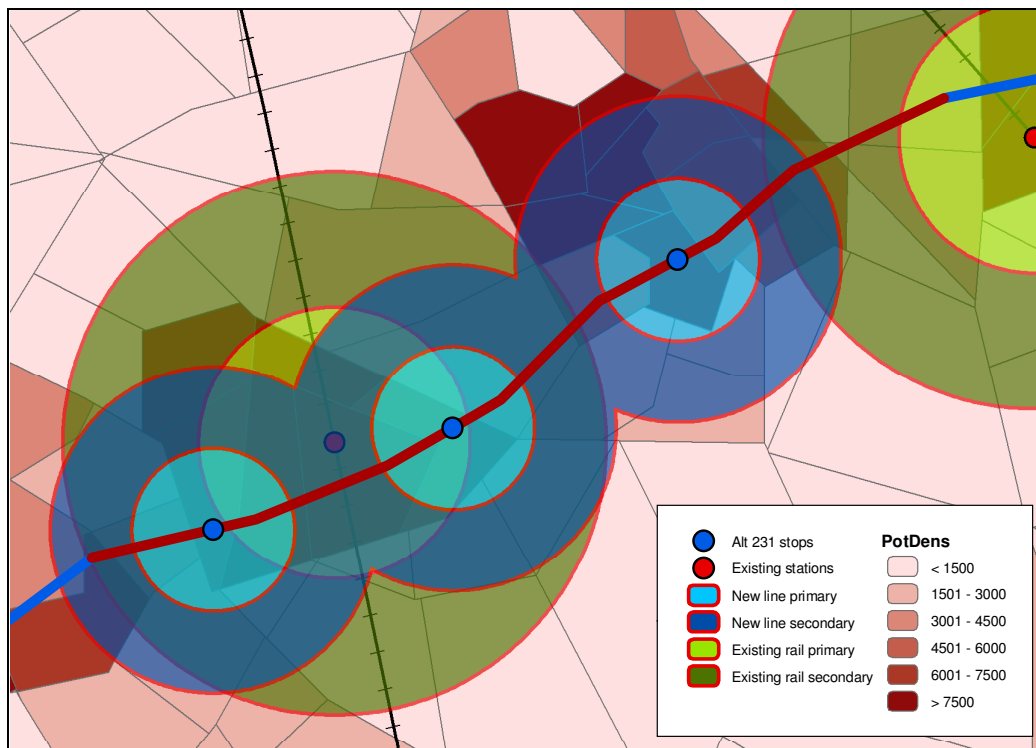


Figure 4.10 – Visual catchment area analysis of Alternative 231 including overlaps from existing rail

Creating the catchment area buffers is only the first of two geoprocessing steps in the catchment area analysis; the second step is the intersection with the catchment area buffers of the new line and underlying travel potential.

Since a geoprocessing analysis should be performed for each alternative it can be a good idea to automate the process, especially if there are many alternatives. Such automation can also provide the documentation for the approach.

When the geoprocessing steps of the catchment area analysis have been performed the subsequent weight allocation and calculation of the associated travel potential for each defined area is a question of data definitions and arithmetic. The final summation of the travel potential for each alternative will provide the decision basis as seen in table 4.3.

	Alternative	Number of stops	Length [km]	Average stop dist. [km]	Initial cost [mill. DKK]	Travel potential	Travel potential / stops	Travel potential / length	Travel potential / initial cost
<i>Section 1</i>	121	2	1.60	0.80	166	3509	1755	2193	21.14
	131	2	1.89	0.95	195	3513	1757	1859	18.02
	132	3	1.89	0.63	198	3784	1261	2002	19.11
<i>Section 2</i>	221	2	3.32	1.66	338	4159	2080	1253	12.30
	222	2	3.32	1.66	338	4011	2006	1208	11.87
	231	3	3.27	1.09	336	4476	1492	1369	13.32
	232	2	3.27	1.64	333	4056	2028	1240	12.18
<i>Section 3</i>	311	2	1.03	0.52	109	6168	3084	5988	56.59
	331	3	1.25	0.42	134	7714	2571	6171	57.57
	332	2	1.25	0.63	131	6081	3041	4865	46.42

Table 4.3 – Catchment area analysis results – Travel potential for stop pattern alternatives

An estimate for the initial cost can provide the best category for decision as it includes both a stop and length dependent contribution (in figure 4.3 the initial cost is based on light rail and is 3 million DKK per stop and 100 mil. DKK per km see “Unit cost for socio-economic analysis in public transport”). For better overview it is good practice to highlight the best alternative in each category (as done with blue in figure 4.3).

4.3.5 Decision process

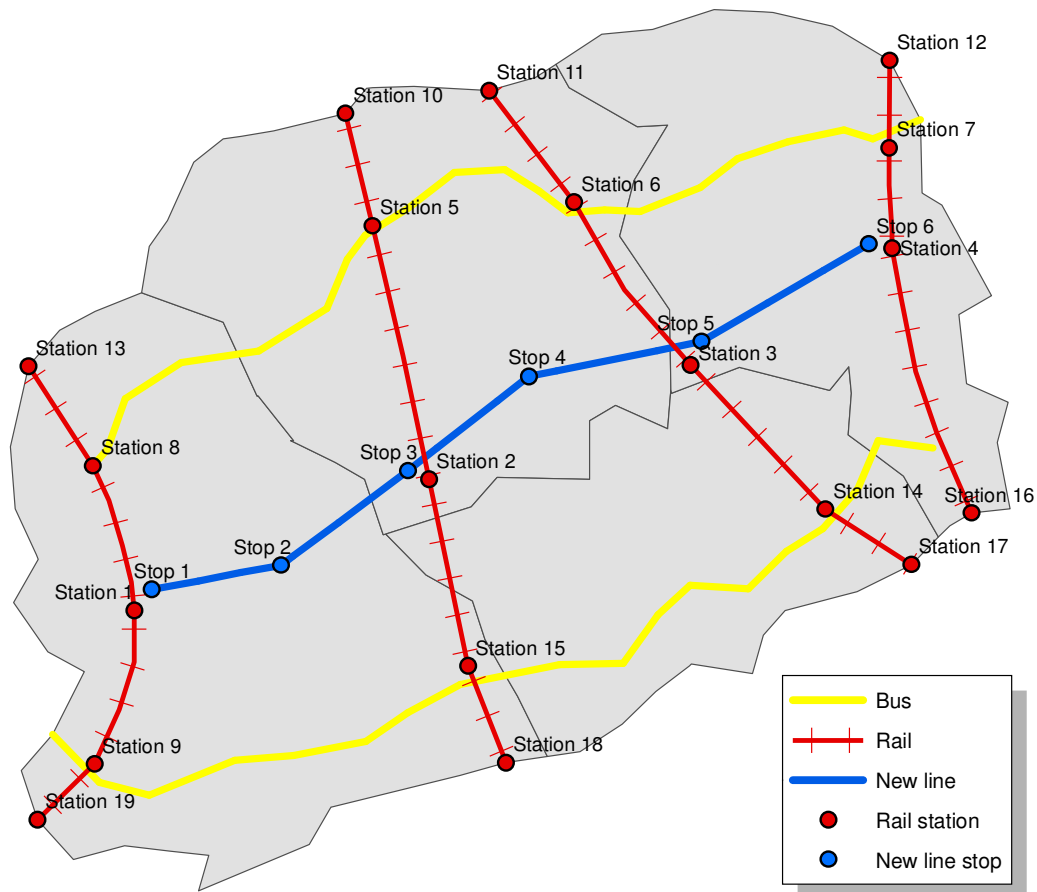
Interpretation of the results from the catchment area analysis can be challenging and how to include them in the decision process is not straightforward. The catchment area analysis results are only decision support and parameters such as transfers, urban development and travel speed are equally important. Therefore, the decision process should include catchment area analysis results as well as logic and argumentation. Table 4.4 gives examples on how to argue from the given result in table 4.3:

General comments	<ul style="list-style-type: none"> <i>In the stop pattern alternatives transfers with existing rail are incorporated for all alternatives and transfers will therefore only be relevant for bus transfers which is less important (negligible here)</i> <i>Urban development can mean development areas but also developing existing urban areas. No such has been defined yet and is negligible here</i>
Section 1	<ul style="list-style-type: none"> <i>Alt 132 has the highest travel potential but also a stop more</i> <i>Alt 121 and Alt 131 are almost even and have the highest travel potentials per stop</i> <i>Alt 121 has the highest travel potential per length and significant higher travel potential per initial cost than the two other alternatives.</i> <i>Alt 121 appears the best and its two stops ensure low travel time</i> <p><i>Chosen alternative: 121</i></p>
Section 2	<ul style="list-style-type: none"> <i>Alt 231 has the highest travel potential but also the highest number of stops</i> <i>Alt 221 has the highest potential per stop but it is only marginal compared to Alt 222 and Alt 232</i> <i>Alt 231 has the highest travel potential per length and per initial cost but it is not that much higher</i> <i>The alternatives are all so equal in the results that it is not possible to make the decision based on the catchment area analysis. Other criteria are needed</i> <p><i>Chosen alternative: 221</i></p>
Section 3	<ul style="list-style-type: none"> <i>Alt 331 has the highest travel potential but also the highest number of stops</i> <i>Alt 311 has the highest travel potential per stop but only marginal better than Alt 332</i> <i>Alt 331 has the highest travel potential per length and per initial cost but not much higher than Alt 331</i> <i>Alt 332 appears to poor to be chosen. Alt 331 is overall a little better than Alt 311 but its extra stop means higher travel time. General Alt 331 does not utilize its extra stop in terms of travel potential hence Alt 311 appears best</i> <p><i>Chosen alternative: 311</i></p>

Table 4.4 – Argumentation for choosing the best alternatives

4.4 Final alignment and stop pattern

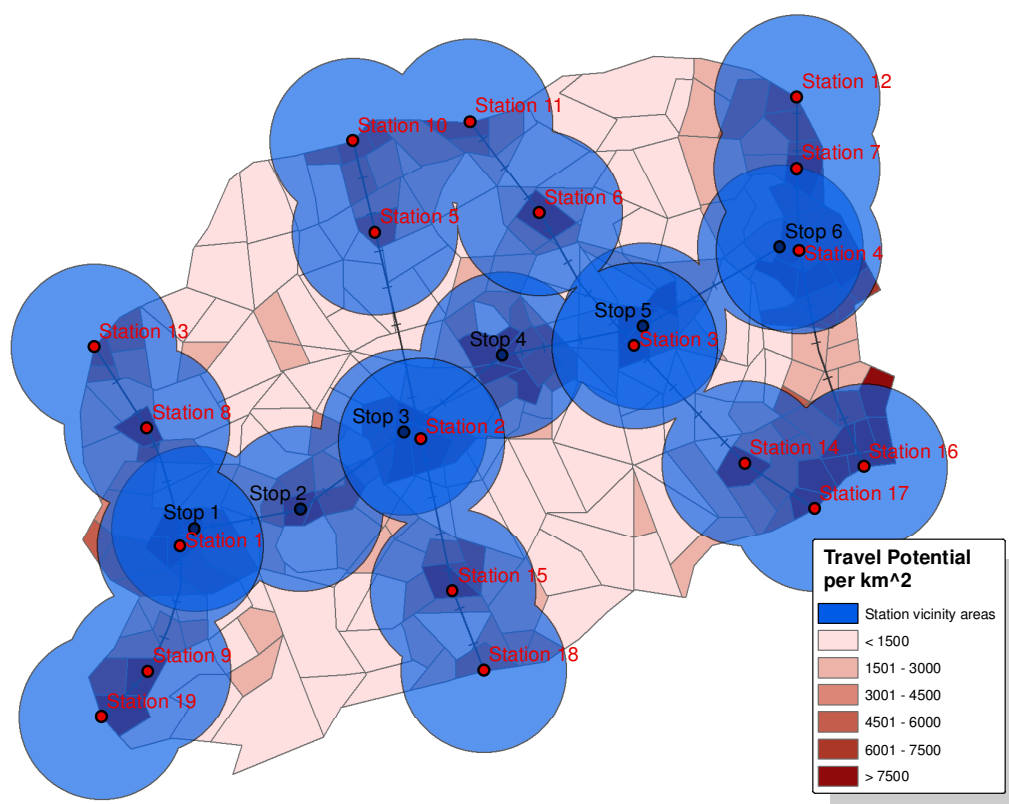
When the best alternatives of each section are chosen the final alignment and stop pattern is given by the sequence of the sections. It is good practice to show the final alignment and stop pattern with basic characteristics as in figure 4.11.



Length: 7.0 km Number of stops: 6 Avg. stop dist: 1.2 km Mixed traffic: 9%
Figure 4.11 – Final alignment and stop pattern of the new line

With alignment and stop pattern decided on the physical planning of the new line is completed. It is good practice to round off by showing improved coverage of public transport and station vicinity because of the new line as seen in figure 4.12⁴.

⁴ Note that not all means of public transport will obtain station vicinity. Under the Danish station vicinity policies it depends on the quality of transport but also politics



**Figure 4.12 – Coverage of high quality public transport with the new line
Station vicinity (1000 m)**

5 Timetable

When planning timetable for at brand new public transport infrastructure there are some key planning parameters to run through. First the travel time for the new line must be determined. Then the plan of operation must be defined. Then transfer connections to other public transport lines must be incorporated and the rolling stock rostering must be fitted preferable in an iterative process. In the sketch planning of public transport this can be done through a simple approach but one should always keep in mind that optimal timetable planning is difficult and can take several years of practice to get a near perfect fit.



Figure 5.1 – Timetable elements

5.1 Travel time

The different components of the travel time are:

- Driving time
- Acceleration and deceleration
- Time supplement (to catch up smaller delays)
- Signal priority
- Dwell time

In the sketch method the driving time is determined and all other components are then added as a supplement in order to get the travel time. Each travel time component must be determined individually.

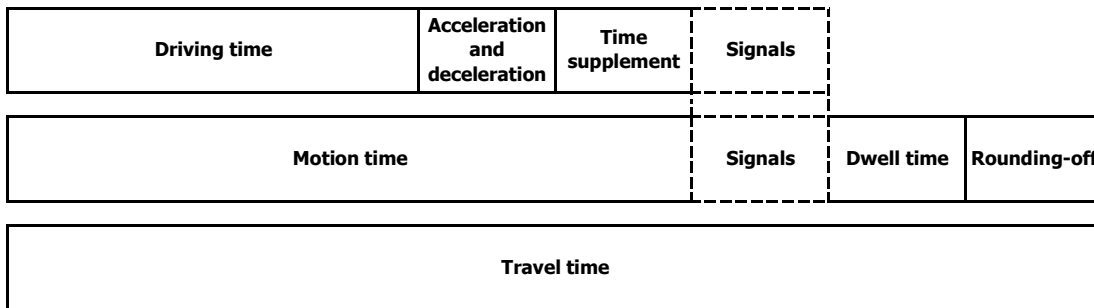


Figure 5.2 – Travel time components and their relation

Time supplements for signals are only relevant for light rail and bus systems.

5.1.1 Driving time

As explained above the acceleration and deceleration is in the sketch method handled as a supplement to the driving time. Because of that, the driving time can easily be calculated through the driven distance and average speed between the stops (without acceleration and deceleration from and to stops) (see figure 5.3). The challenge is to determine the average speed between the stops.

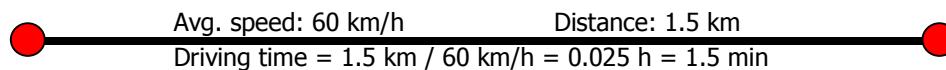


Figure 5.3 – Driving time between two stops

The average speed between stops depends on the mean of transport and its capability. If it is rail with segregated alignment like e.g. urban rail the speed of the vehicles is not obstructed from factors outside the system. If it is a bus system the speed may vary due to obstruction from other traffic. For light rail system it depends on the right-of-way. If the light rail is running partly separated from other traffic in the middle of the road (centre placed reserved lanes) the speed may be up to 20-25 % higher than the allowed speed on the road.

For simplicity, only one speed should be applied between each stop. If the conditions support speed variations between two stops a length depending average can be used for applying one speed for the whole stretch.

When the average speed is determined for all stretches it can be illustrated easy through a speed map (see figure 5.4). This can provide good clarity of the speed applied to the whole alignment.

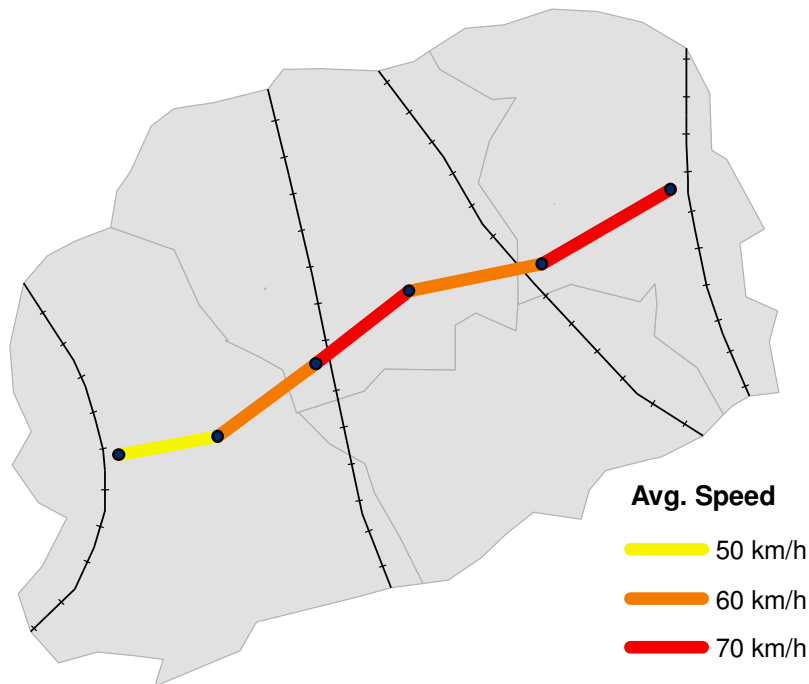


Figure 5.4 – Speed map – average speed between stops

5.1.2 Acceleration and deceleration

Acceleration and deceleration from and to stops should preferable be determined through train simulation software. However, in the sketch method the acceleration and deceleration time supplement to corresponding speeds are already given (see table 5.1). When the average speed is determined between each stop the acceleration and deceleration times are added to the driving time.

Speed [km/h]	Acceleration time* [sec/stop]
25	19
30	20
40	22
50	23
60	25
70	29
75	32
80	33
90	39
100	43
120	59

* The acceleration time includes both acceleration and deceleration at stops, together with opening and closing of doors.

Table 5.1
Acceleration and deceleration supplements
for a given speed (based on a standard light
rail vehicle)

5.1.3 Time supplements

Time supplements are used as time buffer so the system can be punctual even if smaller delays occur. Delays will always occur therefore smaller delays are coped with in the timetable planning.

Running time supplement for a regional double track railway is length depending and can (according to "Capacity promoted initiative for railway systems") be set to:

$$0.05 \text{ min/km}$$

This setting can be used for light rail as well as a compromise between the fact that a light rail system is more flexible than a regional railway and does not have the same strict demand for punctuality, and on the other hand it may have more external factors to obstruct its driving.

5.1.4 Signal priority

For traffic integrated solutions like bus and light rail systems the signal priority issue must be handled. Light rail should be given signal priority on close to all intersections to keep a high overall travel speed. However, sometimes the disbenefit for other traffic may be so large that it is not obtainable – usually when crossing major/arterial roads. The whole alignment must be studied for the possibility of signal priority and it can e.g. be visualized in a map as in figure 5.5.

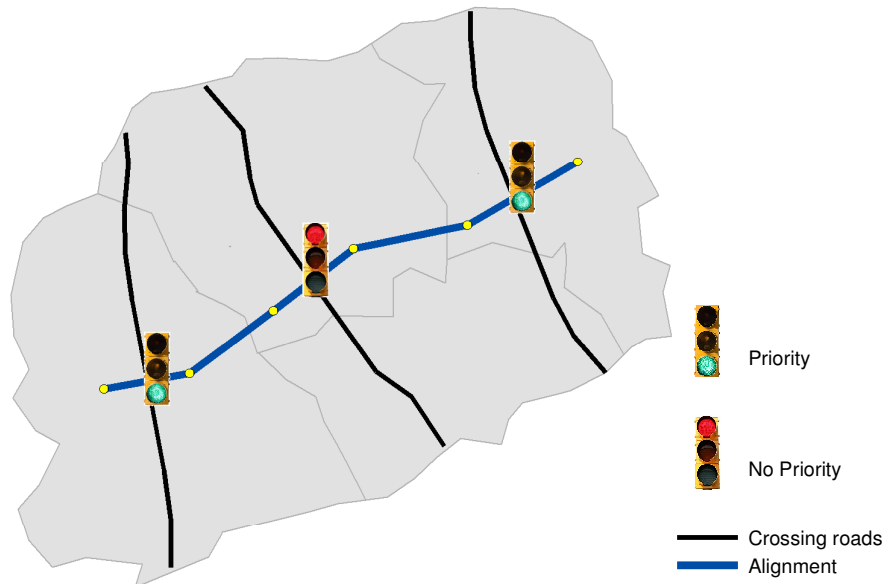


Figure 5.5 – Identification of signal priorities on an alignment

If signal priority can not be obtained a supplement to the driving time on the particular stretch can be added. This time supplement can be handled as a stop without the dwelling time – meaning acceleration and deceleration supplement corresponding to the applied speed. This is based on the assumption that sometimes the vehicle can drive through (if there coincidentally is green light when the vehicle approaches) and sometimes it has to stop and wait for green light (if there coincidentally is red light when the vehicle approaches). If stops are located in continuation of an intersection the supplement can (if necessary at all) be handled in the dwelling time.

5.1.5 Dwell time

Dwell time is the time a vehicle use at stops. Since dwell time mainly depends on the passenger exchange the number of passengers embarking and disembarking has the main influence on the dwelling time. This means also that the dwell time is variable from stop to stop. Beforehand it is difficult to know how many passengers will use the new public transport line at each stop and it is therefore difficult to apply a sufficient dwell time.

To get some idea of the passenger volumes at each stop travel potential for the stops can be used by making a catchment area analysis. Unlike the traditional

catchment area analysis the travel potential must be estimated for each station individually. This means that the issue of overlap between catchment areas of neighboring stations must be considered. This can be handled in two ways, either by making a geographical separation between the catchment areas (and thereby eliminating overlaps) or by handling the overlaps by applying weights after the same principle as in the traditional catchment area analysis (but the actual weights must be different).

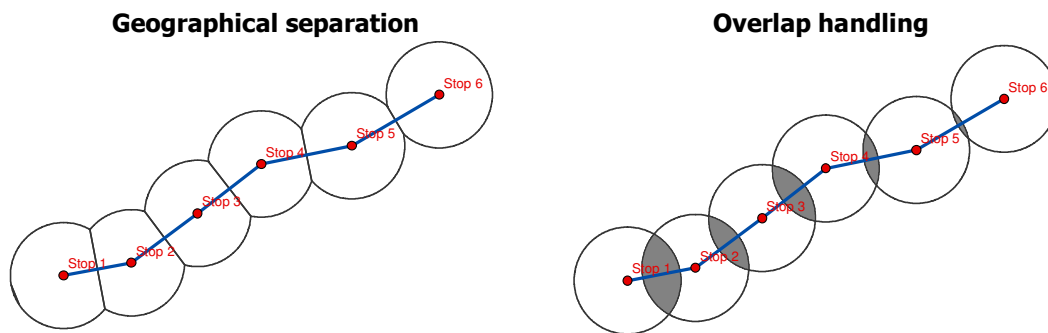


Figure 5.6 – Different ways to handle overlaps between catchment areas of neighboring stop

The geographical separated buffers are more complicated to make but it eases the following overlay analysis where the travel potential is determined. The buffers with the overlap handling are easier to make but the following overlay analysis is more complicated. If the approach with overlap handling is used weights can be applied as in figure 5.7.

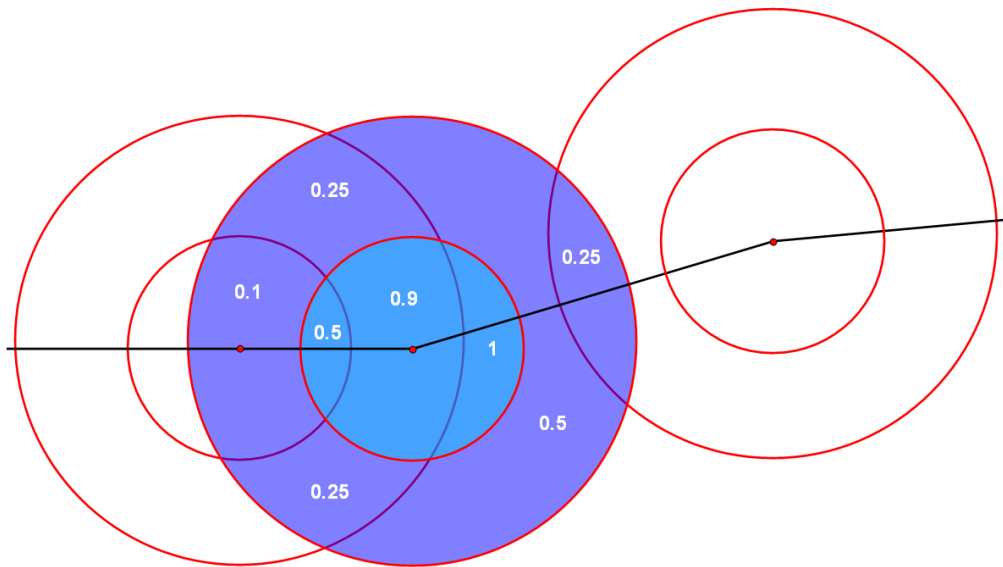


Figure 5.7 – Handling of overlaps from neighboring stops– applied weights

When travel potential for each stop is determined it can be used to determine the dwell time from the rather simple assumption that higher travel potential leads to higher passenger volume and thereby higher dwell time. However, it is important to notice that the effect from transfers is not incorporated. Stops with high expected transfers (e.g. terminals) will have higher passenger volumes and this could lead to higher dwell times. This issue must be taken into account when determining the dwell times.

There is not definite correlation between travel potential and dwell time. It is a matter of defining a level and looking at the interrelationship between levels of travel potential. Good practice is to work with a minimum dwell time no matter how low the travel potential may be. This is to ensure the least time for a passenger exchange and that there is time for e.g. exchange of passengers with prams or bicycles.

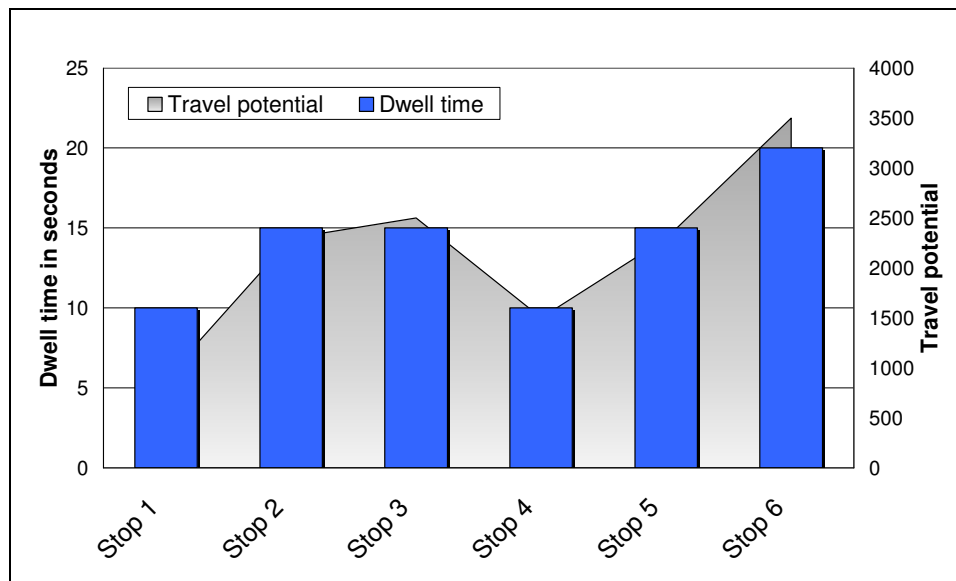


Figure 5.8 – Dwell time based on travel potential for each stop (excluding transfer)

As opposed to figure 5.8 dwell time for end stops is not needed to be implemented in the travel time since the layover time can be utilized for passenger exchange.

5.1.6 Travel time summation

When the driving time and the supplements are determined the travel time can be found through summation as seen in table 5.2.

	Avg. Speed	Length	Driving time	Accl./Decl time	Dwell time	Running time suppl.	Signal	Travel time	Travel time	Round-off travel time	Acc. Travel time
	[km/h]	[km]	[sec]	[sec]	[sec]	[sec]	[sec]	[sec]	[min]	[min]	[min]
Stop 1 - Stop 2	50	1.53	110	23	0	5	0	138	2.3	3	3
Stop 2 - Stop 3	60	1.23	74	25	15	4	0	117	2.0	2	5
Stop 3 - Stop 4	70	2.00	103	29	15	6	32	185	3.1	3	8
Stop 4 - Stop 5	60	1.23	74	25	10	4	0	112	1.9	2	10
Stop 5 - Stop 6	70	1.03	53	29	15	3	0	100	1.7	2	12

Table 5.2 – Travel time summation

A temporary timetable can now be presented (see table 5.3). The temporary timetable is actually just the accumulated travel time but it forms the basis for the final timetable where the exact minutes of departure are determined through transfer connections.

Stop 1	Stop 2	Stop 3	Stop 4	Stop 5	Stop 6
0	3	5	8	10	12
12	9	7	4	2	0

Table 5.3 – Temporary timetable (the minutes of departure are not yet determined)

5.1.7 Comparison of travel time with existing public transport service

An important factor for introducing a new public transport service is to reduce travel time compared to the existing service in the corridor. The overall impact of this is best investigated through traffic modeling but that is normally not available at this stage of the planning process. When planning light rail systems the comparison can relatively simple be made since light rail drives in streets and often directly replace an existing bus. A travel time graph can be used to view the differences and how fast the light rail will be compared to the existing bus (see figure 5.9).

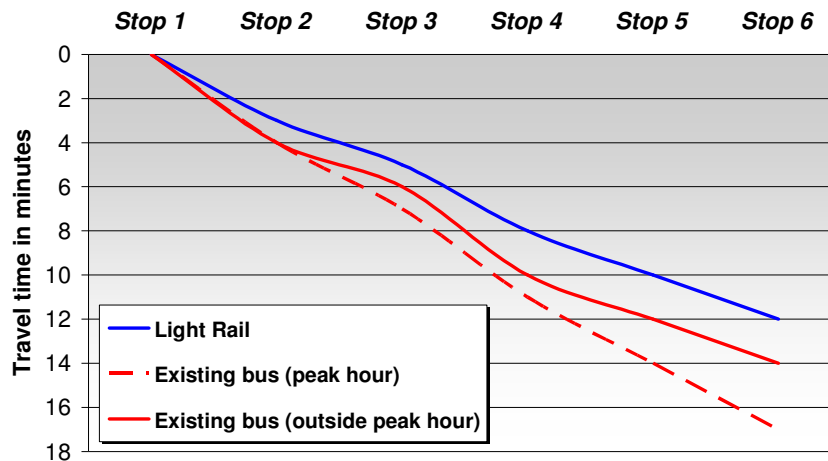


Figure 5.9 – Travel time graph – comparison between light rail and existing bus in one direction

If the light rail is not (significant) faster than the bus the project will most likely not be viable and it should lead to considerations whether to opt out some of the least attractive stops in order to get lower overall travel time.

5.2 Plan of operation

The plan of operation consists of two elements that are more or less correlated:

- Frequency
- Line pattern

5.2.1 Frequency

Determining the frequency of a new public transport system is not always easy since it is a trade-off between customer service and operation cost. When designing light rail timetables a glance at other urban rail with similar characteristics (radial- or ring function, stop distance, degree of urbanization etc.) can be beneficial to get an idea of the proper frequency. Also the determination of complementary bus service in the corridor has an influence. A rule of thumb is that the overall service in the corridor must not be worsened. So even though light rail has higher capacity than the existing bus the frequency must not be lower than the existing service unless the interaction with the supplementing bus service is properly designed.

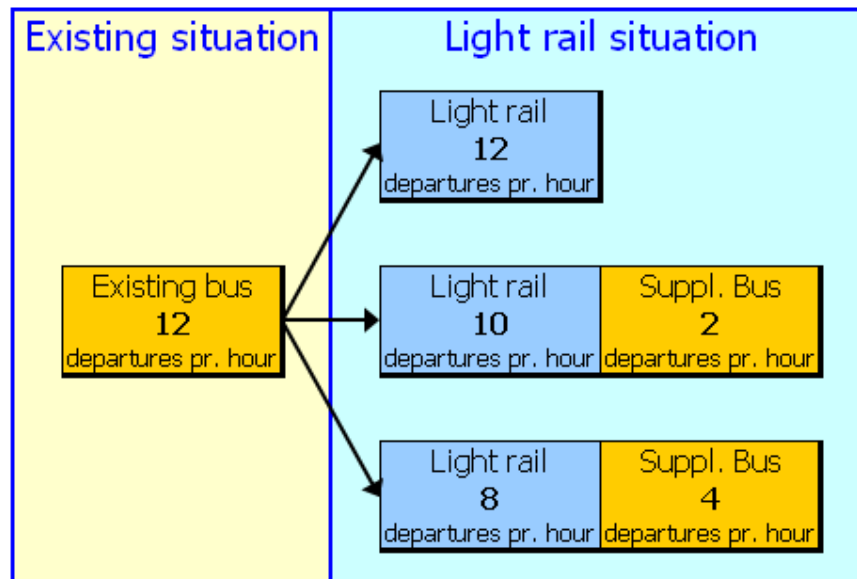


Figure 5.10 – Examples of how to keep existing service with a light rail

Complementary bus service is usually needed to keep good accessibility to public transport in the corridor since the average stop distance is often higher for light rail than for busses.

Supply should fit demand so the frequency ought to vary during the day. For instance with higher service in daytime, and/or peak hours and less in night time. However, it is crucial that the frequency follows the frequency of the public transport lines where transfers are possible to keep a favorable transfer connection (more of this in subsection 5.3 Transfer connections) e.g. a frequency of 15 min is not optimal if the frequency of the corresponding public transport line is 20 min (then 10 min or 20 min will be better).

5.2.2 Line pattern

A traditional line pattern provides service for all stops with all departures (figure 5.11a). This provides simpler planning and operation and also more clarity for customers. However, many corridors support an alternative line pattern. This could be skip-stop-service where every other departure only services the most important stops resulting in a slow and a fast line variant (see figure 5.11b).

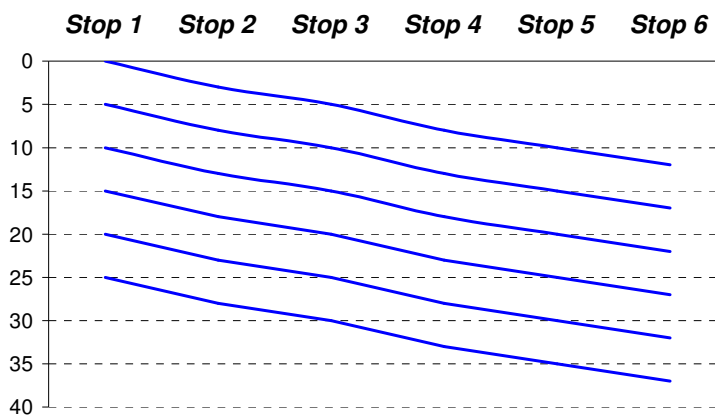


Figure 5.11a
Traditional line pattern
(all-stop-service)

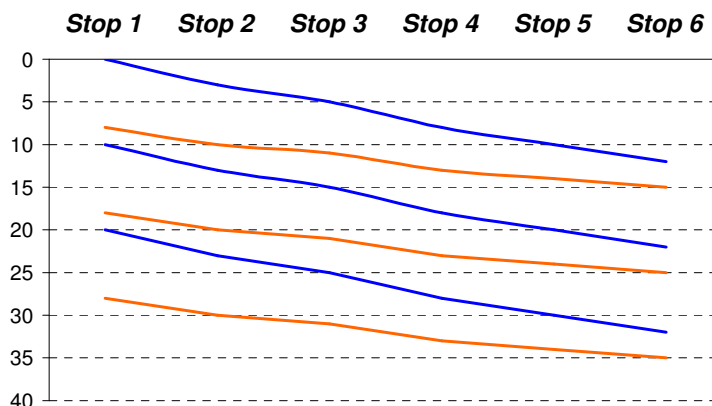


Figure 5.11b
Fast and slow line pattern
(skip-stop-service)

It could also be service based frequencies where every other departure only services the most passenger intensive stretch (double frequency) (see table 5.4).

Stop 1	Stop 2	Stop 3	Stop 4	Stop 5	Stop 6
0	3	5	8	10	12
–	–	10	13	15	17
10	13	15	18	20	22
–	–	20	23	25	27
20	23	25	28	30	32
–	–	30	33	35	37
30	33	35	38	40	42
–	–	40	43	45	47

Table 5.4 – Service based frequency

The specifics of the investigated corridor determine which line pattern is suitable. Suiting the line pattern to the demands of the corridor will result in a better viability for the overall project.

5.3 Transfer connections

Fitting of transfer connections⁵ is performed to minimize waiting times in transfers and through that lower the total travel time for transferring passengers. However, it is not always necessary to make the fittings, it depends on other factors. First of all there must be connection to other public transport lines which is elementary. Second, the frequency must not be too high (5 minute frequency is too high). Often the fittings are done to the evening/night time schedule since frequencies are lower and high waiting times may occur.

The fittings should mostly be done in a hierarchy based on the mean of transport where lower quality transport is fitted to higher quality transport (e.g. bus is fitted to light rail and light rail is fitted to conventional rail). If there are parallel routes for longer distances these should not depart and arrive at the same time. Instead, these routes should be evenly distributed so a regular headway is achieved (see figure 5.12).

⁵ French: correspondance

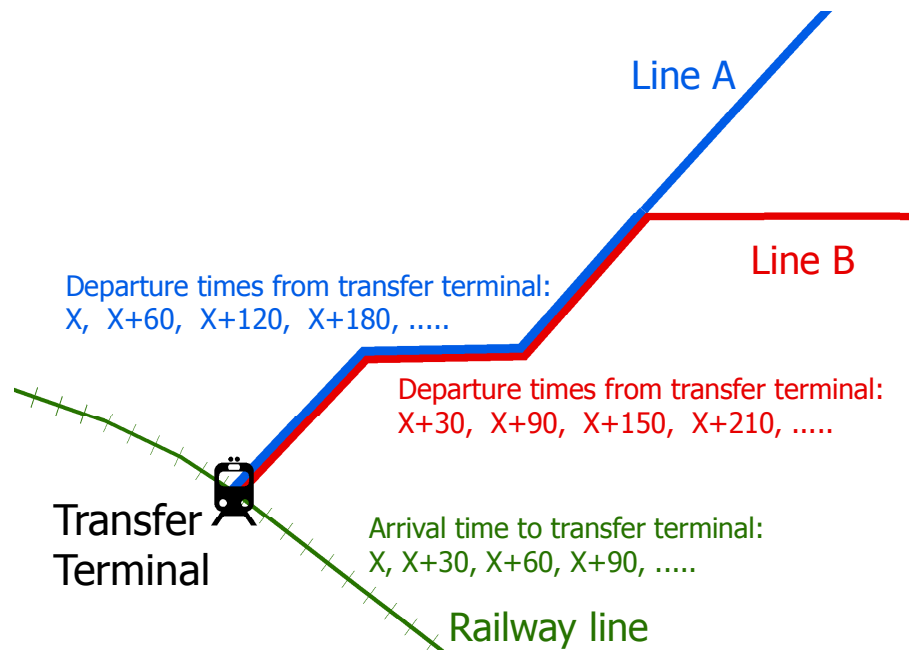


Figure 5.12 – Displacement of departures for two parallel lines to make a better transfer connection with a railway line – Frequencies: Railway line 30 minutes, Other lines 60 minutes – Zero transfer time applied

The first thing to do when planning transfer connections to a new line is to identify the important transfers (see figure 5.13). The importance of a transfer is dominated by expected passenger loads. For a light rail project important transfers will usually be connections to other railways but it can in more rare cases also mean connection to important strategic bus lines.

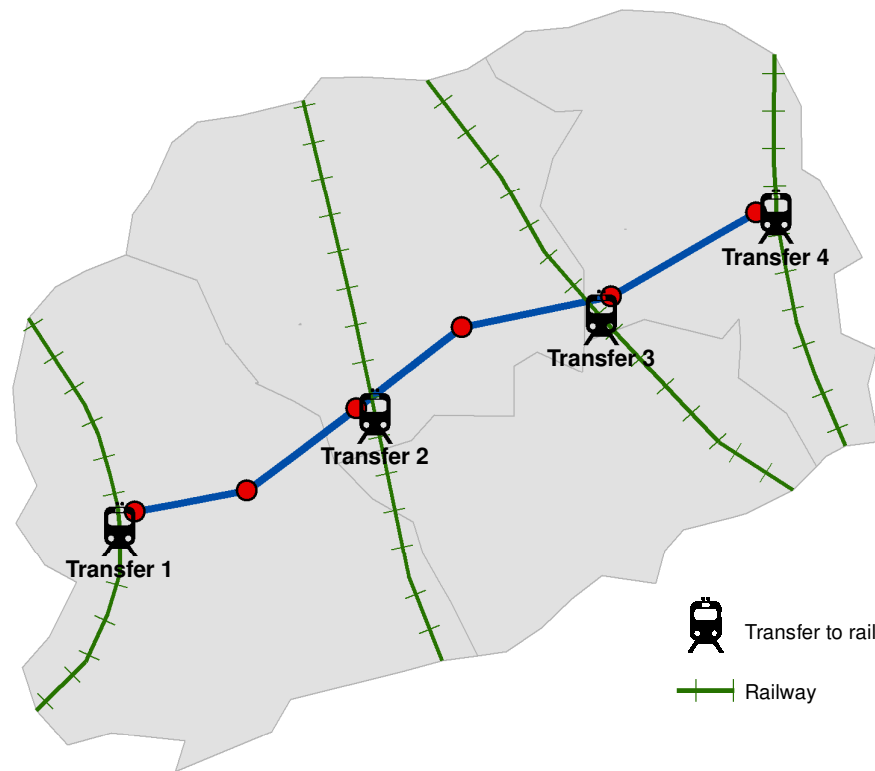


Figure 5.13 – Identification and location of important transfers (here transfer to rail) – Multiple important transfers

Next thing to do is to determine the transfer time at each transfer terminal which means the walking time from platform to platform. This is a fixed time for each terminal but it must be taken into consideration since it is a part of the transfer.

Transfer 1:	2 min
Transfer 2:	3 min
Transfer 3:	2 min
Transfer 4:	3 min

Table 5.5 – Transfer times at the designated important transfers⁶

Then the approach of the fitting must be decided. If there is only one important transfer the fitting is quite easy done to that. If there are important transfers in the

⁶ In this example transfer times are 2-3 minutes which is common but higher transfer times (4-5 minutes) are not uncommon; especially at larger terminals, regional train stations and/or terminals where transfer conditions simply are poor

ends of the new line the fittings are also relatively easy done. If there are multiple important transfers both in the middle of the line and in the ends the fitting gets more complicated. There are two basic principles of transfer connections. One is further travel with the existing line (here referred to as rail) and the other is further travel with the new line (see figure 5.14). Which principle is dominant depends on the travel pattern of the passengers. One principle may be dominant in the morning whereas the other may be dominant in the afternoon. Over a whole day they are equally dominant and can therefore be difficult to take into account when having/planning a regular interval timetable for the whole day.

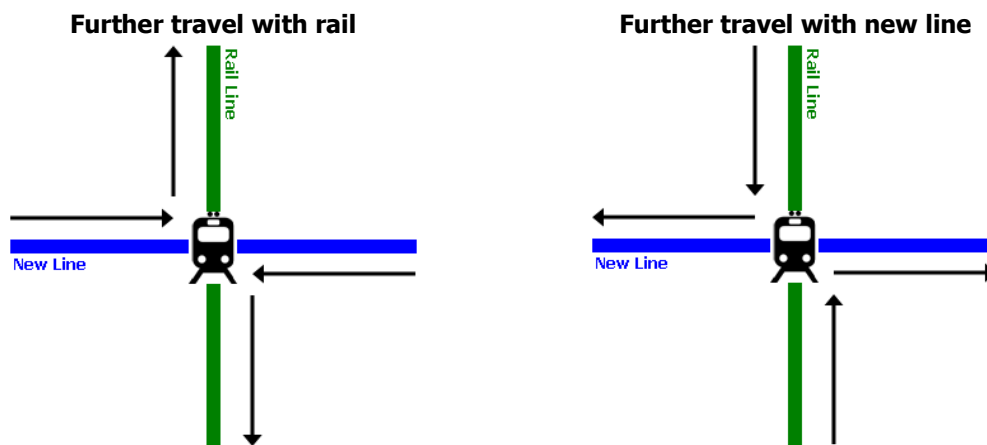


Figure 5.14 – Principles of transfer connections

With many important transfers it can be beneficial with a sketch optimization model that contains timetables for all the including lines (or at least when they depart from the investigated transfer stations). By investigating one direction and one principle at a time and then trying different minutes of departure the sketch model can calculate the lowest total waiting time and its appertaining minute of departure (see example of a sketch model in figure 5.6 and its results in figure 5.15).

Waiting times in minutes															
New Line				Transfer 1		Transfer 2		Transfer 3		Transfer 4					
	Travel time	Minute of departure	Transfer time	Northbound	Southbound	Northbound	Southbound	Northbound	Southbound	Northbound	Southbound				
Stop 1	0	6	2	0	4										
Stop 3	5	11	3			16	8								
Stop 5	10	16	2					9	8						
Stop 6	12	18	3							18	5				
Weight				1.25	1.5	1	1.5	1	1.25	1	1				
Weighted				0	6	16	12	9	10	18	5				
Minute of departure:				6		Total waiting time:				68		Weighted waiting time:		76	

Table 5.6 – Sketch transfer optimization model

Different weights can be applied as an attempt to rank the importance (highest passenger volumes) of the involved transfers.

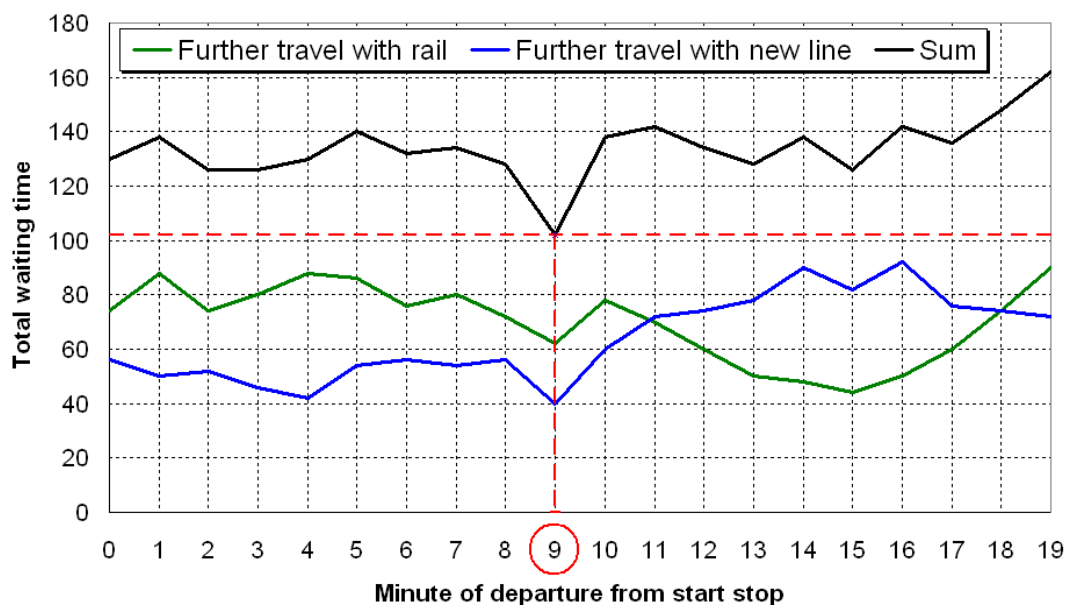


Figure 5.15 – Lowest total waiting time in one direction occur when departing at the ninth minute (20 minutes frequency)

As earlier mentioned, the fitting of transfer connections is normally done to evening/night operation since this is the period where highest waiting times can occur because of the lower frequencies (in figure 5.15 it is done for a 20 minute frequency). However, operating with the same minutes of departure during the whole operation period – both for the new line and for the existing rail lines – means the fittings also apply during lower frequencies, though less relevant.

Both directions must be investigated separately and to get the best minute of departure from both ends of the line the layover time must be adjusted. The layover time is the time a vehicle use at an end stop. There must be applied a minimum layover time which means the least time it takes to make the vehicle operational in the other direction. For bi-directional rail and light rail it means the time the engine driver uses to get from one end of the vehicle to the other or to switch engine driver. The time depends on the length of the vehicle. A rule of thumb for a standard light rail vehicle unit is at least 3 minutes. Additionally, the layover time should contain some time buffer to the minimum layover time so that delays in one direction will not be transferred to the other direction. That time buffer depends on how robust the system generally is (for light rail systems usually a couple of minutes but it can be slackened a bit if in short of time).

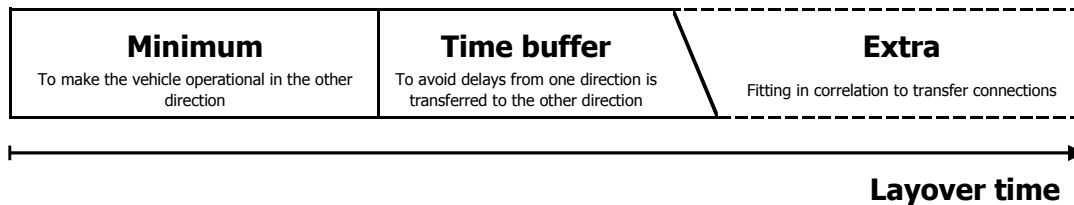


Figure 5.16 – Layover time components

From figure 5.15 the best minute of departure from the passengers' point of view in one of the directions is 9 and if it is assumed that the best minute of departure in the other direction is 6 the travel pattern for a basic vehicle set can be calculated (see figure 5.17):

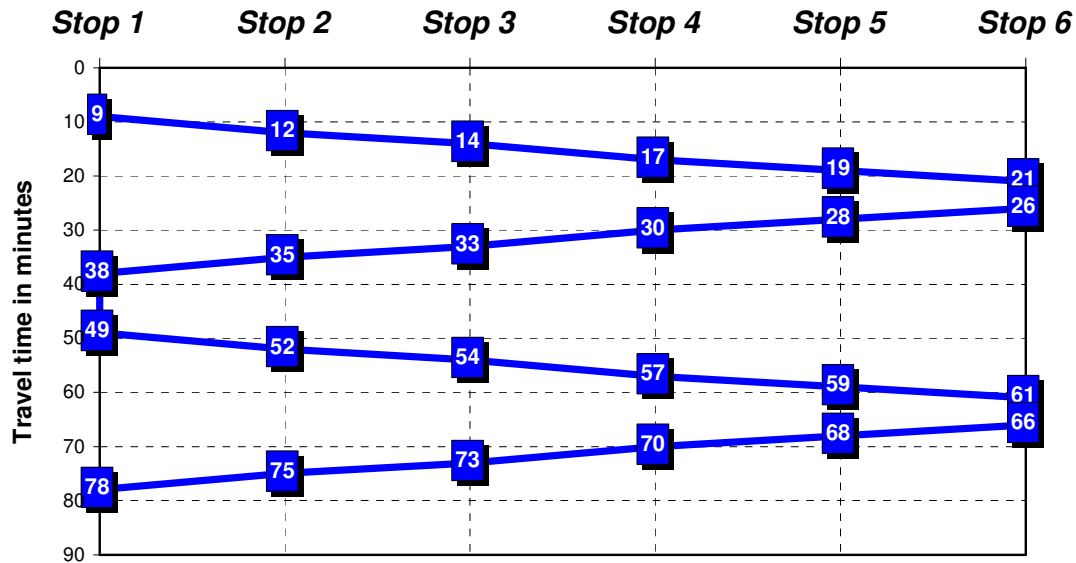


Figure 5.17 – Travel pattern for a basic vehicle set (10 minute frequency)

Note that since the bare minimum layover time is 3 minutes the layover time in Stop 1 must be raised to 11 minutes. This does not mean that another departure cannot occur one minute after the arrival (e.g. at minute 39) it just has to be another vehicle.

The sketch optimization model is a fairly good and simple way to handle the problems of fitting multiple transfer connections, as real optimization models are much more complex.

5.4 Need for rolling stock

When a timetable is planned the next step is to find out how many vehicles are needed to operate the timetable. This procedure is called rolling stock rostering. To do this the round-trip time has to be calculated which is the scheduled circulation time of a vehicle (see figure 5.18):

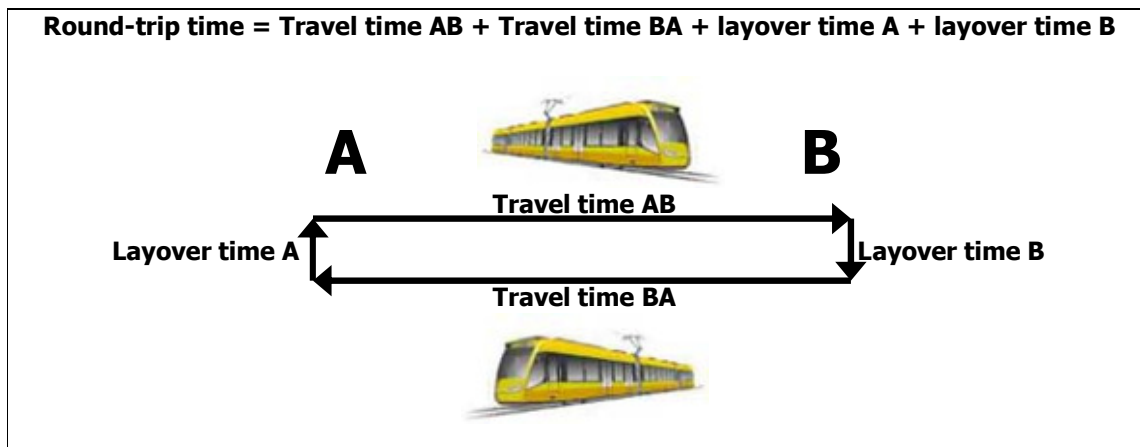


Figure 5.18 – Principle of Round-trip time

Note that the round-trip time always will be a multiple of the frequency.

After that the necessary number of vehicle sets to fulfill the scheduled operation can be found from the round-trip time and the frequency:

Formula 5.1 *Number of vehicle sets for operation = Round-trip time × Frequency*

The highest frequency determines the highest number of vehicle sets that has to be in operation. For busses a vehicle set only consist of one vehicle. This is usually also the case for light rail but like conventional rail a vehicle set can consist of multiple vehicles to increase capacity. The number of vehicles is then determined by multiplying the number of vehicle sets with the number of vehicles per vehicle set.

Additionally, some extra vehicle sets are needed as reserve. A rule of thumb is 10-15% of the operational fleet, but minimum two extra vehicle sets – one for maintenance and one standing by to put into operation in case of an error/damage of one of the vehicle sets in service.

The calculation of the needed rolling stock must be performed after the transfer connections and thereby after the timetable is determined. This is because the layover times – and thereby the timetable – may be affected by the planned connections, which may result in a higher need of rolling stock. However, sometimes a slight worsening for the passengers (e.g. choosing the second best minute of departure instead of the best) can result in a large saving in operation and initial cost because a vehicle set less is needed. As example the layover time off 11 minutes in

Stop 1 in figure 5.17 is a little too high. Another minute of departure than the ninth may lower this layover time thus saving a vehicle set. This feedback mechanism must be taken into account when determining transfer connections and rolling stock rostering.

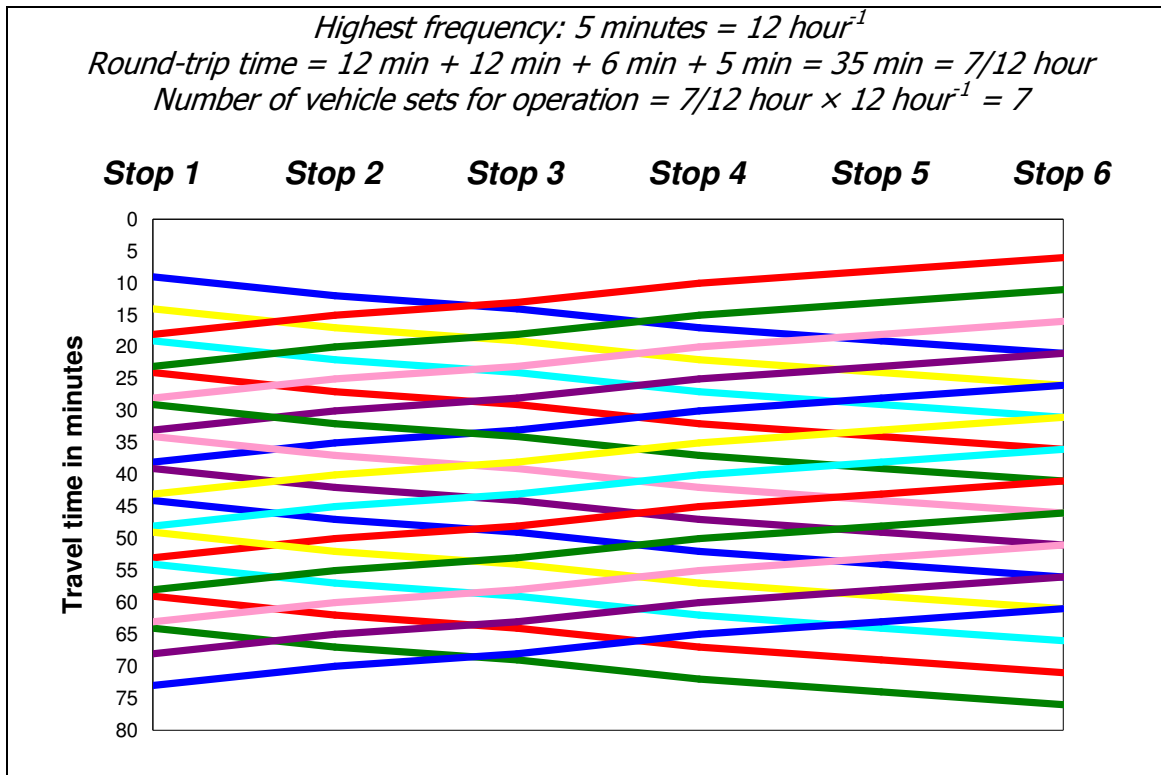


Figure 5.19 – One hour travel pattern for the applied timetable (5 minutes frequency) – each color represents a vehicle set

A graph of the travel pattern (as seen in figure 5.19) can sometimes be useful to visualize the different vehicle sets in operation – in fact it is also possible to count the needed vehicle sets as a quality check.

5.5 Final timetable

When the planning of travel time, plan of operation, transfer connections and calculation of needed rolling stock are completed the final timetable can be presented. Sometimes the primary objective of the timetable planning is to evaluate the new line in traffic modeling. Even so, it is good practice to show the final timetable in a customer friendly version. It could e.g. be built up like existing

timetables for urban rail so the customers are already familiar with the appearance (see figure 5.20).

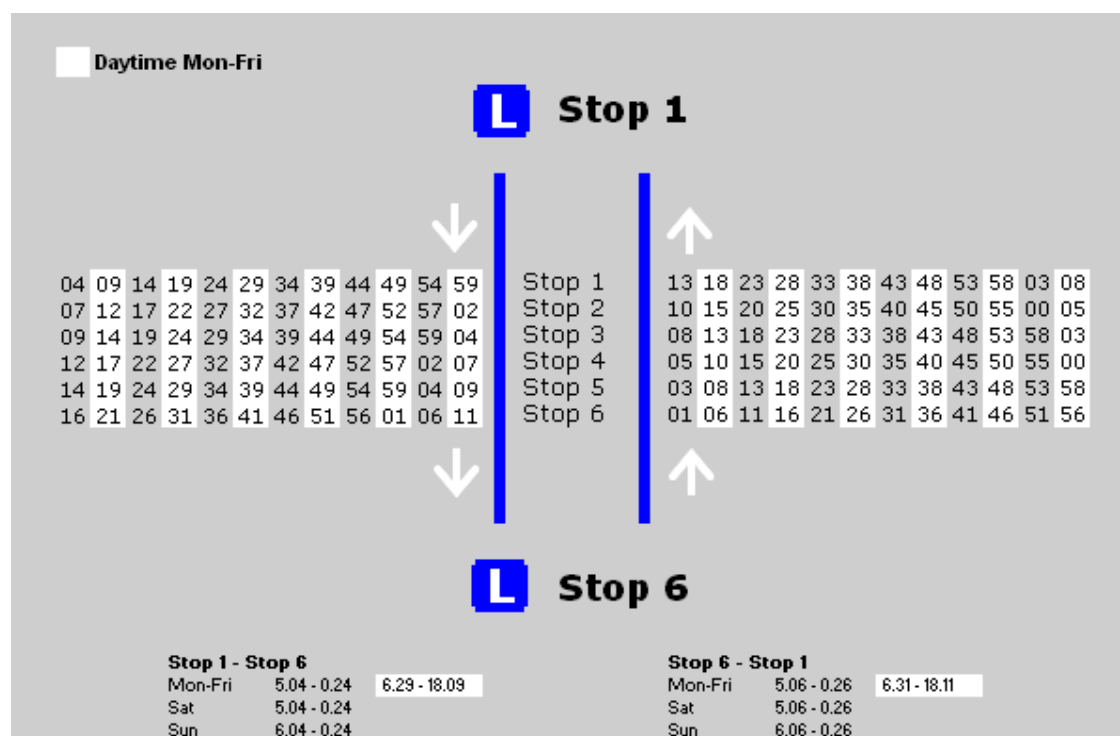


Figure 5.20 – Final timetable – customer version

6 Traffic modeling

When the final timetable has been defined the new line can be evaluated through traffic modeling. Here the traffic modeling only consists of the last stage in the four-stage-model, the assignment stage. The assignments are solely performed on public transport through a timetable-based route choice model (more about the applied model in “A large-scale model system for the Copenhagen-Ringsted railway project”). How the new line and its timetable are implemented in the traffic model is a rather technical issue that will not be addressed here. This chapter instead focuses on the traffic modeling process and how to present output results from the traffic model.

The traffic model takes three superior input data:

- **Network** – lines, stops, timetables, access/egress, transfers
- **Trip matrix** (OD-matrix) – travelers applied to zonal structure
- **Parameters** – different route choice parameters

Usually modeling of different trip purposes will occur. This should be done separately for each trip purpose and it means that there are separate trip matrix and parameters for each trip purpose.

6.1 Preparation

Before the traffic modeling can be performed the input data has to undergo a substantial quality control and the new line has to be implemented in the network. An illustration of the network and input data can be viewed in figure 6.1.

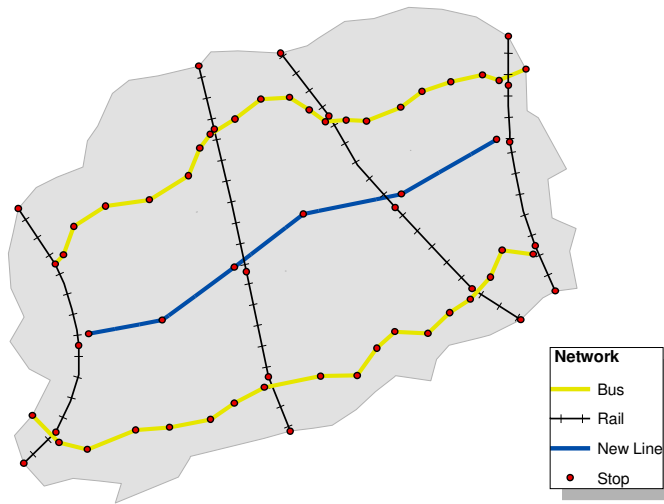


Figure 6.1a
Public transport network for
traffic modeling

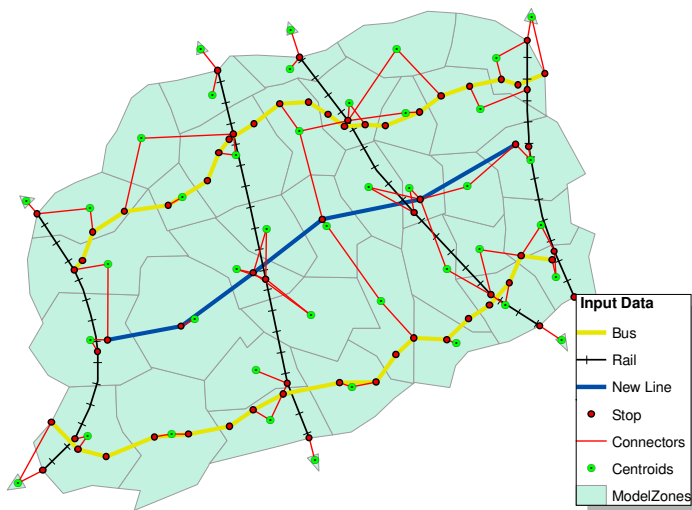


Figure 6.1b
All (GIS based) input data for
traffic modeling

Some of the important issues to consider before starting the route choice assignments are model period (whole day or only a portion of a day e.g. morning rush hour) and number of iterations and launches (detail level vs. calculation times). In the following the model period is morning rush hour (7:00-9:00).

6.1.1 Transfer and access/egress

Another issue is travel time on change edges (transfer links) and connectors (access/egress links). Implementing the new line also means implementation of new

transfers and connectors and the travel time on these must be calculated before running assignments.

Determination of travel time on transfer links is easy since transfers nearly always are conducted by foot. That means applying an average walking speed (e.g. 5 km/h unless there is traffic signals to pass in the transfer) will produce the travel time when divided into the distance of the change edge.

Determination of travel time on connectors is more difficult since access/egress can be conducted by different means of transport usually depending on the distance, where longer distance means faster mean of transport. However, boundaries are fluid and there can not just be applied one mean of transport – and thereby one travel speed – to certain intervals of the distance. The problem calls for an expression where travel time is a continuous function of the distance. It is good practice to develop this function oneself by looking at figures of transport mode to/from stations published by existing rail operators (see e.g. "7 Planning Themes for S-trains"). A more simple approach is to use the following formula to find the travel speed and then derive the travel time:

Formula 6.1

$$TravelSpeed_{Connector} \left(\frac{km}{h} \right) = \sqrt{\frac{Length_{Connector}(m)}{2}}$$

Finding the travel time on connectors by using formula 6.1 will result in a distance/travel time relationship looking as in figure 6.2.

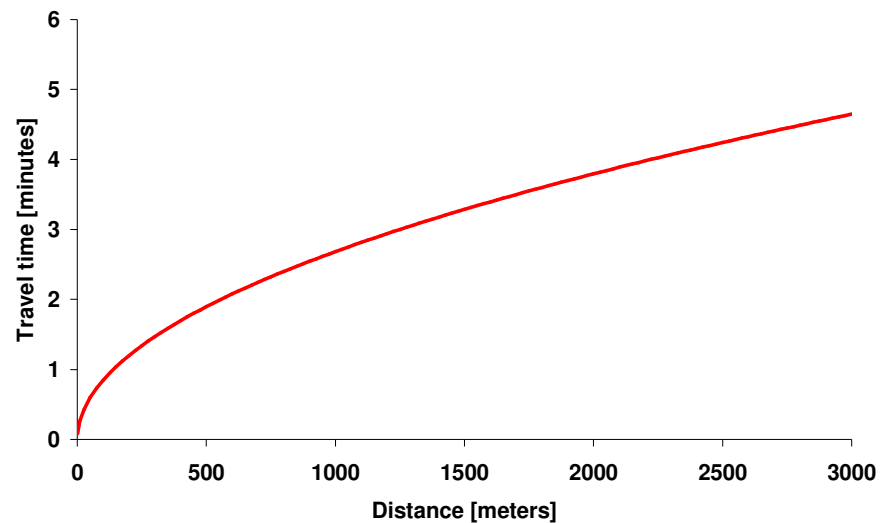


Figure 6.2 – Travel time on connectors as function of connector length

It is always good practice to plot the travel time of all connectors to see which pattern they follow.

Implementation of transfers and connectors need to be done before starting any route choice assignments. In that way their influence in the comparisons between scenarios will be minimized.

6.2 Traffic modeling workflow

When the preliminary preparation has been performed the actual traffic modeling can begin. It consists of five sequential phases as seen in figure 6.3.

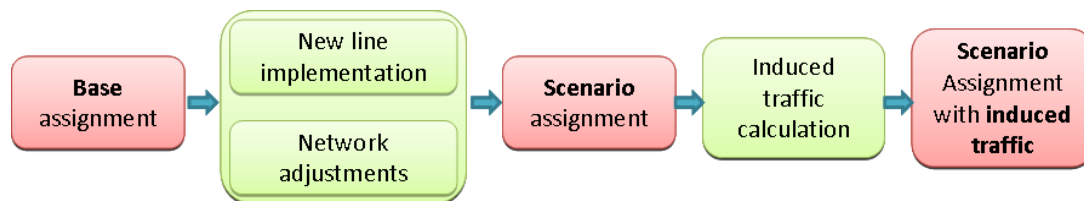


Figure 6.3 – Workflow in traffic modeling

6.2.1 Network adjustments

The network adjustments (seen in figure 6.3) are the modifications to the existing public transport system as a result of the new line. Depending on what type of transport the new line is the adjustments can be minor or major.

A new Metro or urban rail line will usually result in a major rearrangement of the bus system and maybe also of other rail lines. A light rail will generate a smaller demand for adjustments but even minor rearrangements can be complex to implement in the traffic model. Generally, a new light rail will replace most of the service (if not all) of the existing bus line(s) in the corridor and maybe shorten alignments and/or lower frequency in other partly competing bus lines. But it is really all about not worsening the overall service and especially keeping in mind that the average stop distance is often higher for light rail than for busses. Local customers can suffer from poorer accessibility to public transport if the local bus service is closed entirely down. The level of adjustment is therefore very dependent on the conditions in the corridor and the characteristics of the existing bus line(s). Existing rail lines are usually unaffected by a new light rail.

6.3 Handling traffic model results

The traffic model generates some resulting output. In the further analysis of the traffic impact of the new line the most important output data are:

- Traffic volumes on lines/links
- Traffic volumes at stops
- Travel times between all model zones

When all steps in the traffic modeling workflow (figure 6.3) has been performed output data for the base situation, the scenario situation and the scenario situation with induced traffic is accessible.

Since the traffic modeling must be performed on different trip purposes separately the output will also appear separately. To present the complete results output for the different trip purposes must be pooled. This is applicable for passenger volumes where the total number is desirable but for travel time the different trip purposes is easier investigated separately and sometimes it is only necessary to show the most dominating trip purpose (e.g. commuting in the morning rush hour).

To present the effects of the new line comparisons between the base situation and the scenario situation (with induced traffic) is the most relevant. However, before making these comparisons it is good practice to show the effect of the induced traffic. This can be done by comparing the scenario situation with induced traffic with the scenario situation without induced traffic (see table 6.1).

Effect of:	Comparison		
	Situation	Operator	Situation
<i>New line:</i>	Scenario with induced traffic	Absolute	Base
		- / -	
<i>Induced traffic:</i>	Scenario with induced traffic	Absolute	Scenario without induced traffic
		- / -	

Table 6.1 – Comparison of scenario situations to illustrate the effect of the new line and the induced traffic respectively

Investigations of induced traffic can be made by using traffic volumes on lines/links and/or travel times between model zones. The comparison process is practically the same whether it is induced traffic or the effect of the new line that is investigated. How to display these effects by using the important output will be scrutinized in the following chapter. Another good practice regarding induced traffic is to show how many new passengers is generated as seen in table 6.2.

Trip purpose 1:	400
Trip purpose 2:	25
Trip purpose 3:	50
Total	475

Table 6.2 – New trips generated by induced traffic (7:00-9:00)

The numbers can be found by summarizing all new travelers between all zones.

6.3.1 Traffic volumes on lines/links

Traffic volumes on lines/links are a good way to get an overview of the impacts of the new line in the public transport network. Good practice is to start by showing a map with passenger volumes of the whole network for the existing situation (base situation) (see figure 6.4). This sort of map can indicate whether the traffic model is giving a realistic image of the existing situation and pick up severe errors (this should therefore be done prior to assigning any scenario situation).

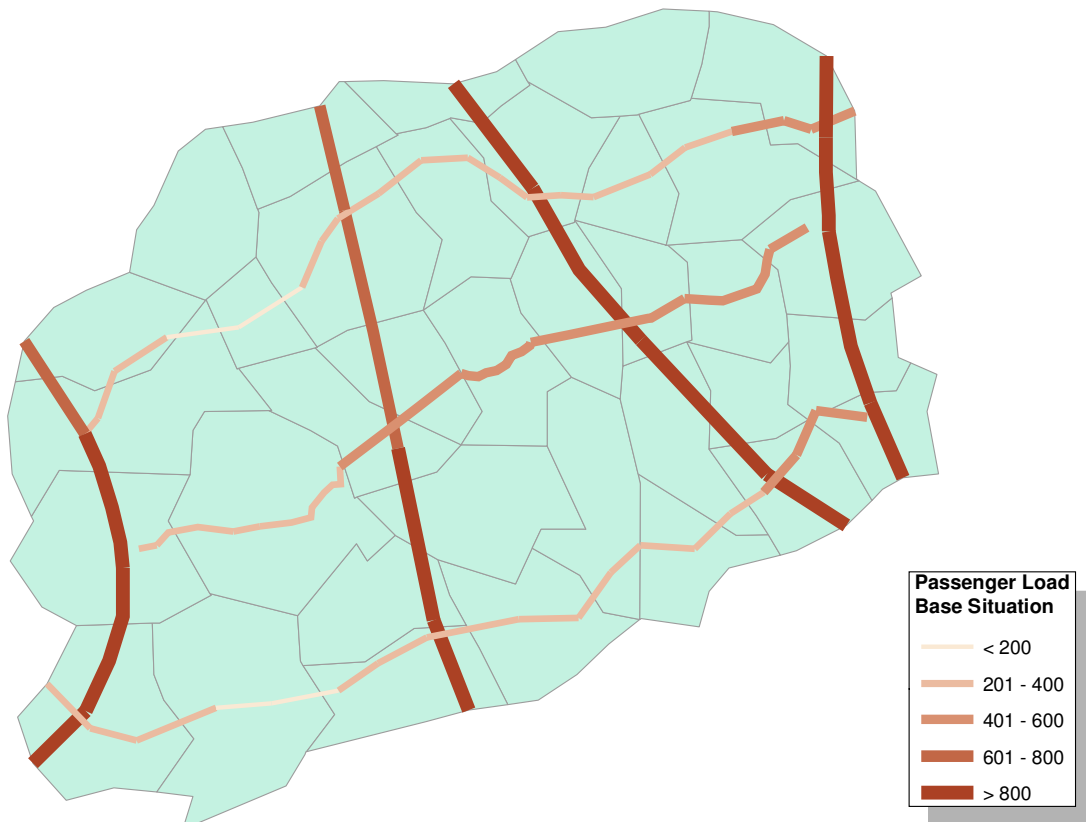


Figure 6.4 – Traffic flows for existing situation (7:00-9:00)

A rough quality control can be performed from figure 6.4 e.g. if expected heavy lines also carry a high number of passengers, if rail has higher number of passengers than bus and in general that it looks reasonable and probable. This can be combined with your own knowledge about the traffic flow and by having a travel potential layer active to see that there generally is more traffic where the travel potential is high.

When it is observed that the traffic model produce reasonable traffic flows for the base situation the scenario situation can be modeled and the comparison between the two can begin.

The traffic volumes on lines/links can be used to view the impact of the new line in the network. This becomes most evident when showing differences in traffic flows between the two situations as seen in figure 6.5.

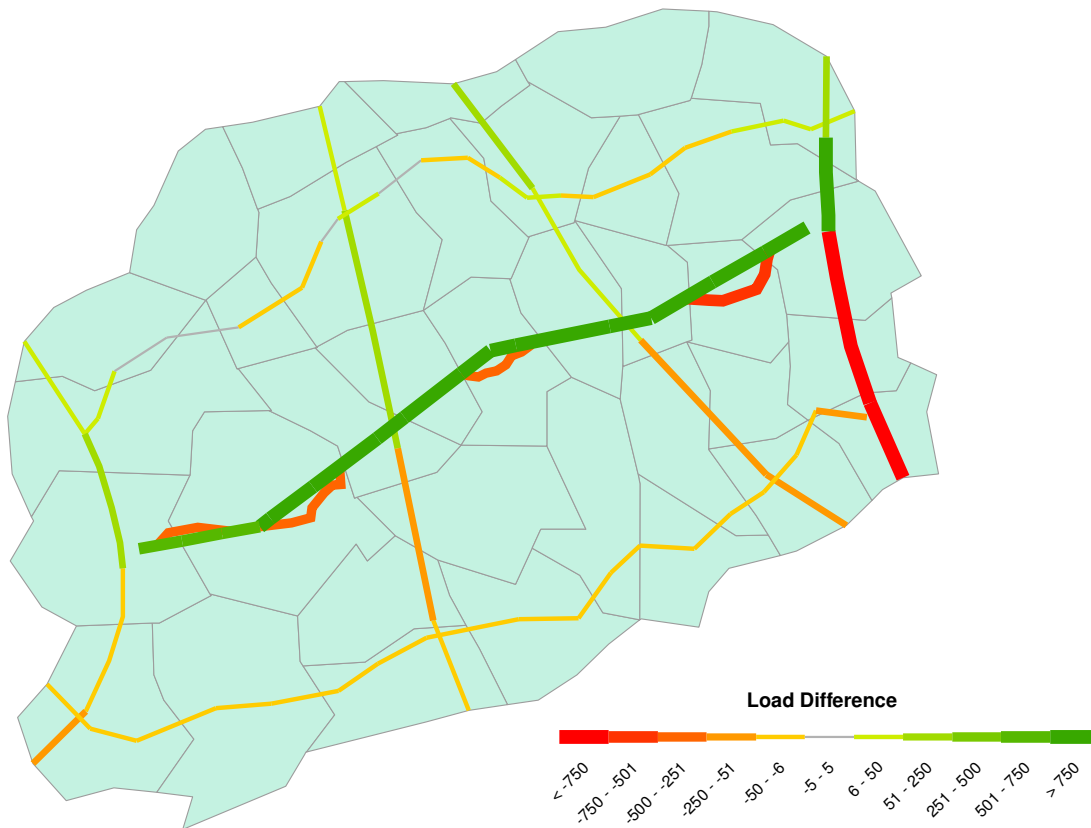


Figure 6.5 – Differences in passenger flows between existing situation (base) and situation with the new line (scenario) (7:00-9:00)

From such a map it is possible to get indications of which lines/links will gain passengers when implementing the new line and which lines/links will be relieved. However, it is important not to over interpret and focus too much on details but only centre on the superior effects. A rough quality check of the network adjustments can also be conducted – if some important lines or lines far away from the new line loose more passengers than expected it may be due to too many closures of lines/stops.

It is also possible to isolate the new line to view the passenger volumes on the new line solely as seen on figure 6.6.

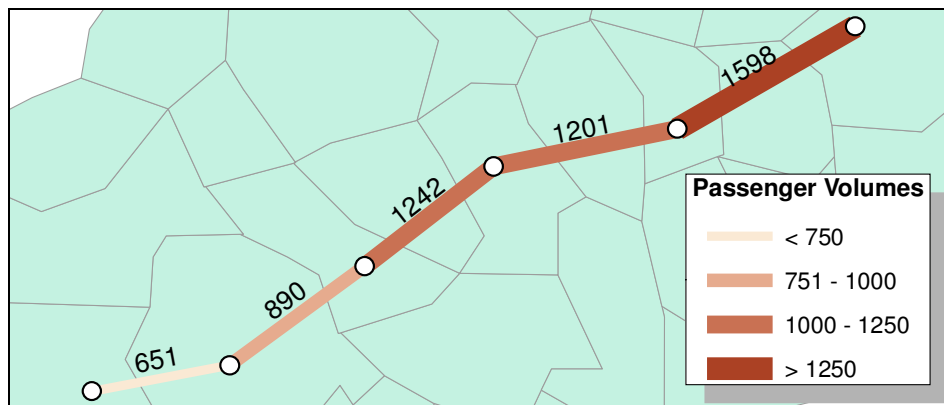


Figure 6.6 – Passenger volumes on the new line (7:00-9:00)

6.3.2 Traffic volumes at stops

Traffic volumes at stops are simply the boarding and alighting of the new line. It can be used to illustrate passenger exchange at each stop as seen in figure 6.7.

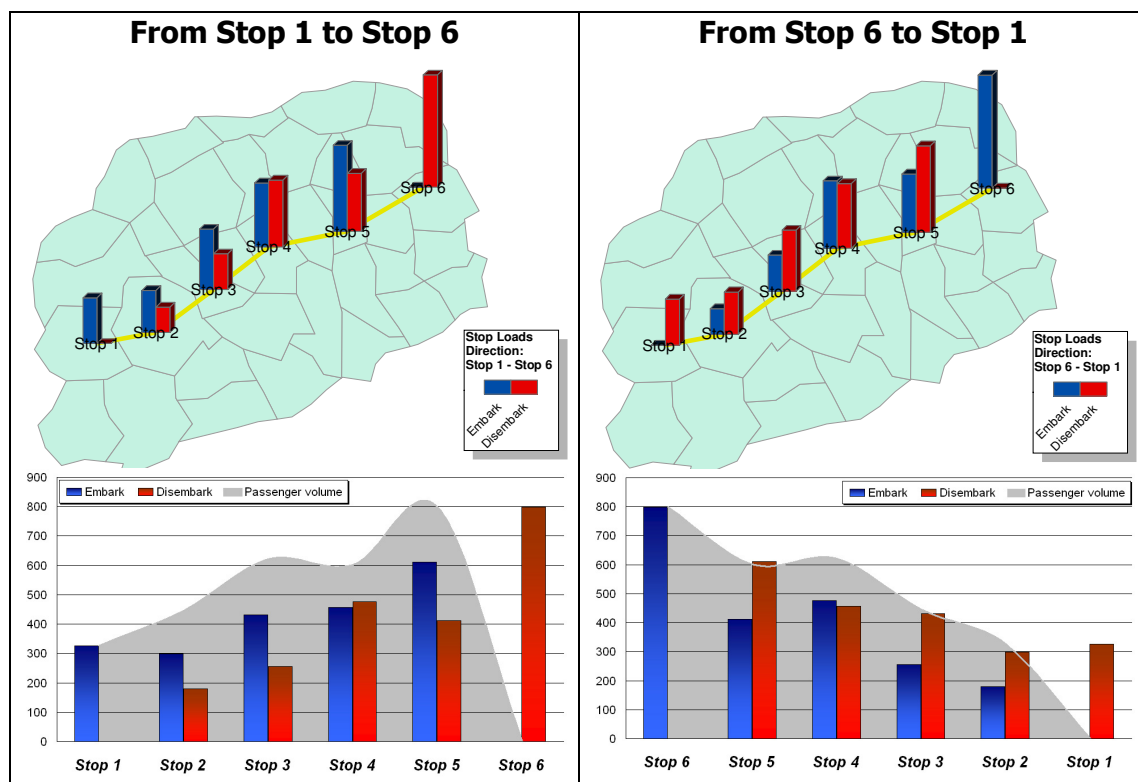


Figure 6.7 – Stop loads and passenger volumes in both directions (7:00-9:00)

It is good practice to show both embarking and disembarking passengers in both directions especially if the model period is resulting in asymmetric passenger flows (all periods that are not an entire day).

From traffic volumes at stops it is possible to extract the total number of passengers on the new line by summarizing the embarking passengers.

Number of passengers (7:00-9:00): 4245

In the case where the model period is only a portion of a whole day (e.g. morning rush hour 7:00-9:00 like here) this figure can be revalued to work day level and from work day level to average annual day level to get the daily number of passengers. The daily number of passengers is a good and comparative indicator of the new lines attractiveness and it should later be used to calculate operating economy. The daily number of passengers of the new line can also be compared with the existing bus line in the corridor (the one that the new line will replace) to see the passenger effect of the new line. Assumptions on how to revalue figures to daily and yearly level are presented in chapter 7 Project Appraisal where also the daily number of passengers will be presented.

6.3.3 Travel time between all zones

Travel time and traffic between all zones is obtained from a cost matrix and also characterized as the level of service (LOS). It can be used to illustrate changes in regional accessibility and mobility based on travel time as a result of the new line as seen on figure 6.8.

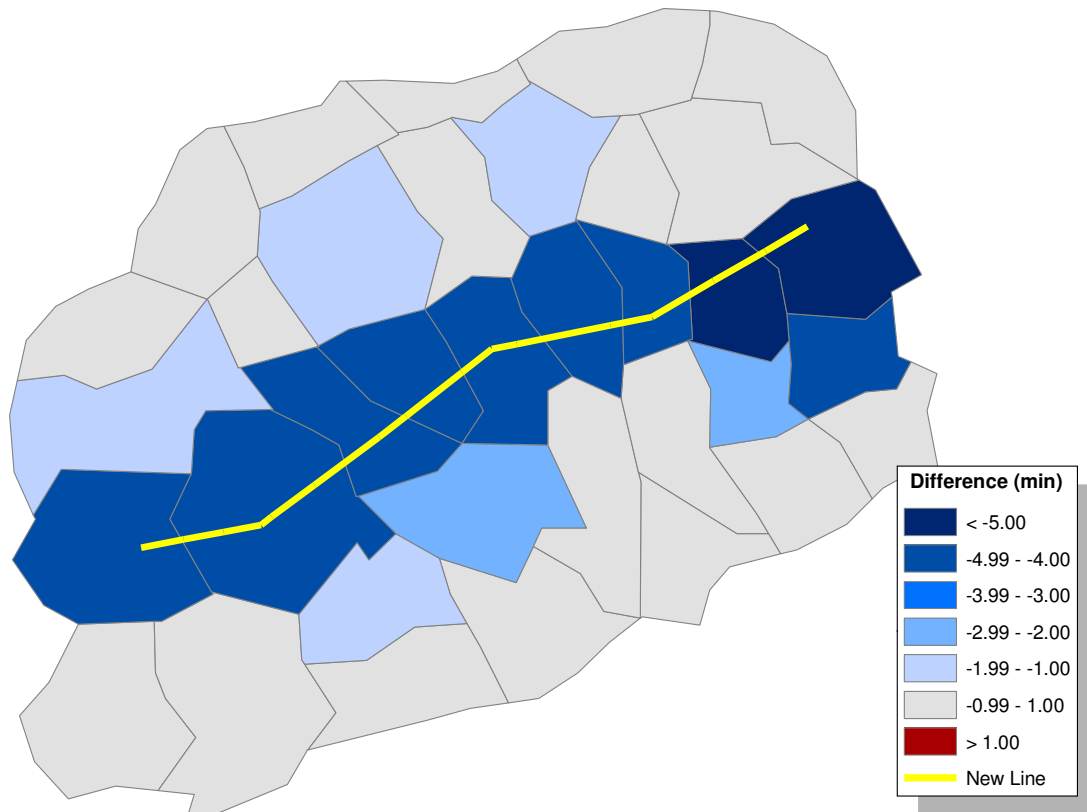


Figure 6.8 – Differences in regional accessibility (travel time) between existing situation (base) and situation with the new line (scenario)

Such a map can show in which areas the impact of the new line will be highest in terms of reduced travel time. However, the map can also be used as a quality check of the network adjustments – if areas far away from the new line will have a major disbenefit it may be due to too many restrictions in the existing service.

If there is a focus location in the corridor that demands special attention (a terminal, university, hospital etc.) the travel time to or from the zone where the special location is located can be investigated as seen on figure 6.9:

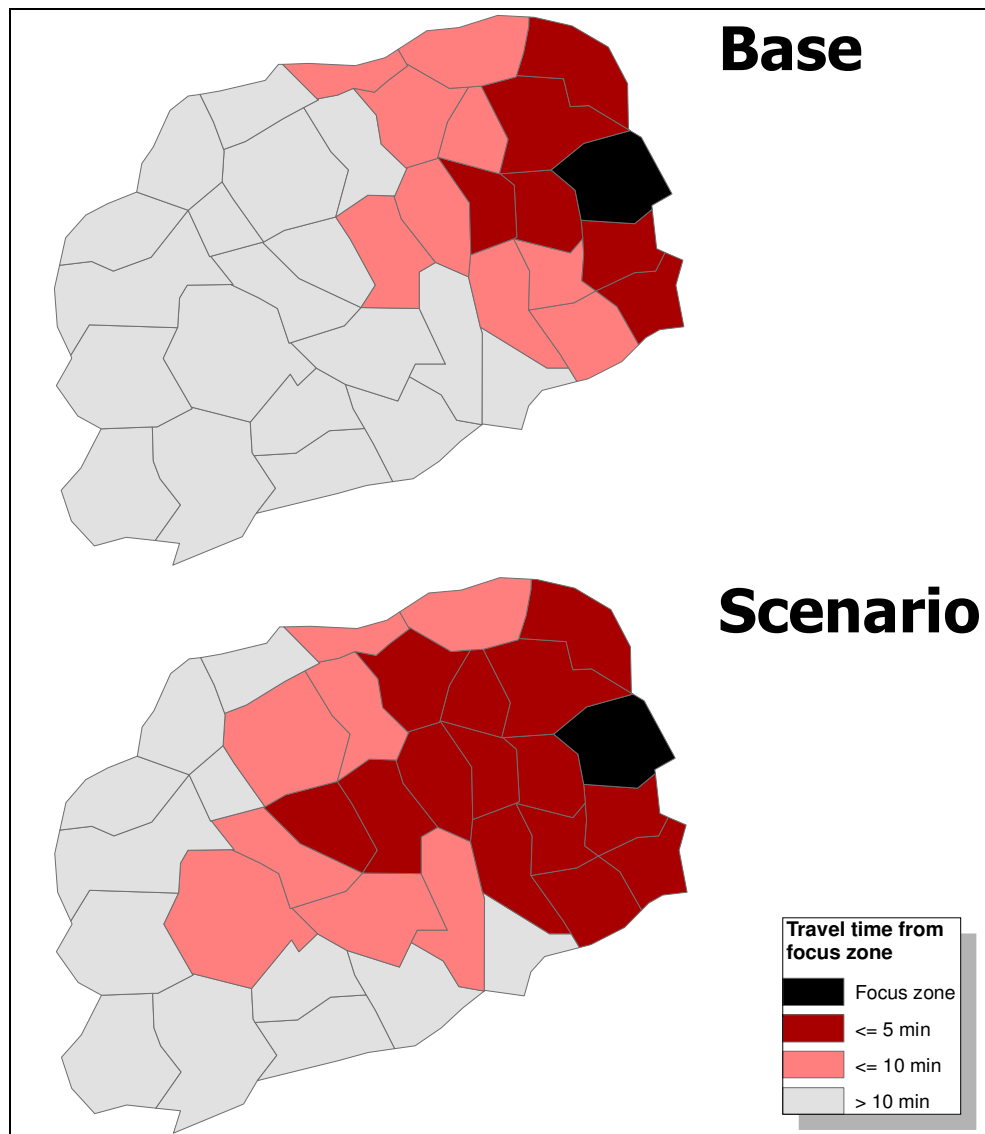


Figure 6.9 – Travel time from focus zone – existing situation (Base) and situation with new line (Scenario)

This can show how the new line can improve the contact radius from a specific location in terms of reduced travel time.

From the travel time and the travel between all zones the total time consumption in the network can be found. If this is done for both base situation and scenario

situation it provides a quick look at the time savings. Later in the socio-economic analysis the time savings are priced but the actual time savings can be an indicator whether the new line has a positive impact on the total travel time in the network (see table 6.3).

	Trip purpose 1	Trip purpose 2	Trip purpose 3	Total
	[hours]	[hours]	[hours]	[hours]
<i>Base situation</i>	8,606	269	1,451	10,326
<i>Scenario situation</i>	8,164	254	1,390	9,808
Savings	442	15	61	518

Table 6.3 – Time consumption and savings in the network (7:00-9:00)

Visualization of the traffic modeling output is important to investigate the traffic and travel time impacts of the public transport system. But the output is also used to determine socio-economic and operating economy for the new line (see following chapter 7 Project Appraisal).

7 Project appraisal

The most relevant project appraisal approaches are the economic evaluations. The most important of these regarding public transport are the socio-economic cost-benefit analysis and the operating economy. There are also other important evaluation elements that not are directly economic assessed e.g. strategic impacts. This chapter focuses on the economic appraisal of the new line from a socio-economic and operating approach but in the end of the chapter the strategic impacts will also be reviewed.

7.1 Preliminary definitions

Before starting the actual economic analysis there are some preliminary definitions to keep track of since they are important for making proper calculations. It is primarily about discounting and revaluation.

7.1.1 Discounting

Unit prices for use in economic assessments are rarely all from the same year thus the prices are quoted in different price levels. To compare all elements at once the prices have to be discounted to a common price level (the calculation year). This can be done as in formula 7.1 (c.f. "Note about socio-economic calculation"):

Formula 7.1
$$K_0 = K_n(1 + i)^{\pm n}$$

Where:

K_0 is the value in the calculation year

K_n is the value in year n to be discounted

i is the (average) yearly inflation in %

n is the number of years to be discounted

+ if discounting forward in time

- if discounting backwards in time

The formula 7.1 is easy to use but it can be associated with some trouble finding the inflation over a multi-annual period. However, a short-cut can be made since Statistics Denmark has a price calculator on their website. This can directly discount an entered amount from and to desired years ("Statistics Denmark").

Good practice is to discount to – and make the whole analysis in – the year where the price for the heaviest effect is given. In that way the uncertainties in the discounting will be minimized.

7.1.2 Revaluation

Economic evaluations are usually performed at a yearly level or maybe at a daily level. This means that all figures incorporated in the analysis must be listed in either prices per year or prices per day. If the traffic modeling has been performed on a portion of a whole day e.g. morning rush hour the output results have to be revalued to daily level and further to yearly level. Here are some general guidelines:

- *In the morning rush hour (7:00-9:00) 20%-25% of the traffic of a whole working day is carried through*
- *A Working Day Traffic (WDT) corresponds to $[1.18;1.22] \times \text{Annual Average Day Traffic (AADT) or Annual Traffic} / [300;310]$*

With these two expressions it is possible to revalue morning rush hour figures to yearly figures⁷. But since they both contain a coefficient interval – and results are sensitive to it – it is good practice to make sensitivity analysis of results that have been revalued. How to do so will be presented in the following examinations of operating economy and socio-economics.

7.2 Costs

The cost for the new line is divided into two parts: the initial cost which is a one time investment and the operating cost which is the running cost for operation and maintenance.

7.2.1 Initial Cost

The fixed asset investment of the new line covers both construction cost, cable and pipe rearrangement and purchasing of the needed rolling stock and it is here referred to as the initial cost. Unit costs are used to calculate the initial cost (c.f. "Unit costs for socio-economic analysis in public transport") and they are all discounted to the calculation year (here 2004). It is good practice to list all implemented figures in a clear way that leaves no doubt how the initial cost as well as intermediate costs were calculated (see table 7.1).

⁷ Evaluating only the morning rush hour is not as precise as evaluating the entire day but it gives a good indication of the project's viability

Type	Cost [mil. DKK]	Quantity	Total [mil. DKK]
<i>Track equipment</i>			
Tracks	10.8 km ⁻¹	7 km	76
Power	8.7 km ⁻¹	7 km	61
Signals	2.2 km ⁻¹	7 km	15
<i>Stops</i>			
Station at-grade	3.3 apiece	6	20
<i>Road modification</i>	45.5 km ⁻¹	3 km	137
<i>Repository and CMC</i>	175.4 apiece	1	175
<i>Cable and pipe rearrangement</i>			
Drain pipes	4.3 km ⁻¹	7 km	30
Telephone and electric cables	2.2 km ⁻¹	7 km	15
District heating pipelines	27.1 km ⁻¹	7 km	189
Water lines	6.5 km ⁻¹	7 km	45
Gas ducts	6.5 km ⁻¹	7 km	45
<i>Rolling stock</i>	15.2 per unit	9	137
Passenger info, communication etc.	0.3 per unit	9	3
Total			949

Table 7.1 – Initial cost for the new line (unit cost for light rail – 2004-prices)

7.2.2 Operating cost

Operating cost covers the running cost for the new line which means operation and maintenance. It is assessed on an annual basis and unit costs are used to calculate the operating cost (c.f. "Unit costs for socio-economic analysis in public transport"). Like the initial cost this should also be presented in a clear way so it is evident how the operating cost appears (see table 7.2).

Type	Cost	Quantity	Total [mil. DKK]
<i>Track equipment</i>	3% of construction cost for tracks	152 mil. DKK	4.6
<i>Stops</i>	2% of construction cost for stops	20 mil. DKK	0.4
<i>Rolling stock</i>	55.7 DKK per vehicle km	812784 vehicle km	45.3
<i>Reinvestments</i>	0.5% of reduced initial cost*	484 mil. DKK	2.4
Total			52.7

* Initial cost excluding rolling stock and cable and pipe rearrangement

Table 7.2 – Operating cost for the new line (unit cost for light rail – 2004-prices)

7.3 Operating economy

Operating economy is simply an assessment of operating cost and revenue for the new line. The operating revenue consists of ticket sales and it is calculated from

number of passengers on the new line and a price per embarking passenger (c.f. "Operating economy for public transport").

The result can be presented as operating profit as well as level of self-financing (farebox recovery ratio) (see table 7.3). If the operating profit is negative the new line requires subsidies to operate. It is good practice to compare the operating economy of the new line with existing bus lines.

Track Equipment	-4.6 mio. kr.
Stops	-0.4 mio. kr.
Rolling stock	-45.3 mio. kr.
Reinvestments	-2.4 mio. kr.
Ticket revenue	39.6 mio. kr.
Operating profit	-13.1 mio. kr.
Level of self-financing	75 %

Table 7.3 – Annual operating economy for the new line (light rail – 2004-prices)

The ticket revenue is calculated from the number of passengers at the new line. In this case the number of passengers is based on traffic modeling of the morning rush hour (7:00-9:00) and therefore it has had to be revalued to annual level. As earlier mentioned (chapter 6 Traffic modeling, 6.3.2 Traffic volumes at stops) this is breeding ground for a sensitivity analysis of the revaluations impact on the operating economy (see table 7.4).

<i>Passengers morning rush hour (7:00-9:00):</i>	4245		
<i>Share of working day:</i>	0.25	0.225	0.20
<i>Passengers working day:</i>	16980	18867	21225
<i>Working day to year:</i>	300	305	310
<i>Passengers annual [mil.]:</i>	5.1	5.8	6.6
<i>Income per passenger [DKK]:</i>	6.89		
<i>Operating revenue [mil. DKK]:</i>	35.1	39.6	45.3
Operating profit [mil. DKK]:	-17.6	-13.1	-7.4
Level of self-financing:	67%	75%	86%

Table 7.4 – Sensitivity analysis of revaluating operating economy (2004-prices)

From the calculations leading to table 7.4 it is possible to extract the daily number of passengers which is a good figure to present (as mentioned in chapter 6 Traffic modeling, 6.3.2 Traffic volumes at stops). The daily number of passengers is the Average Annual Day Traffic (AADT) on the new line.

Daily number of passengers = 15,770 [13,969;18,030]

Regarding the operating economy the setting of the income per passenger can also be subject to a sensitivity analysis. This is because no light rail and consequently no light rail value for the income per passenger exist in the Copenhagen public transport system (c.f. "Operating economy for public transport"). In table 7.3 and table 7.4 the calculation of the operating economy for the new line is simply based on an income per passenger that is half bus half Metro ($\frac{1}{2} \times 5.61 + \frac{1}{2} \times 8.16 = 6.89$) but in reality it is not to know whether a light rail value will lean towards the bus value or the metro value. Therefore, the setting of the income per passenger and its resulting impact on the operating economy for the new line can be investigated (see figure 7.1).

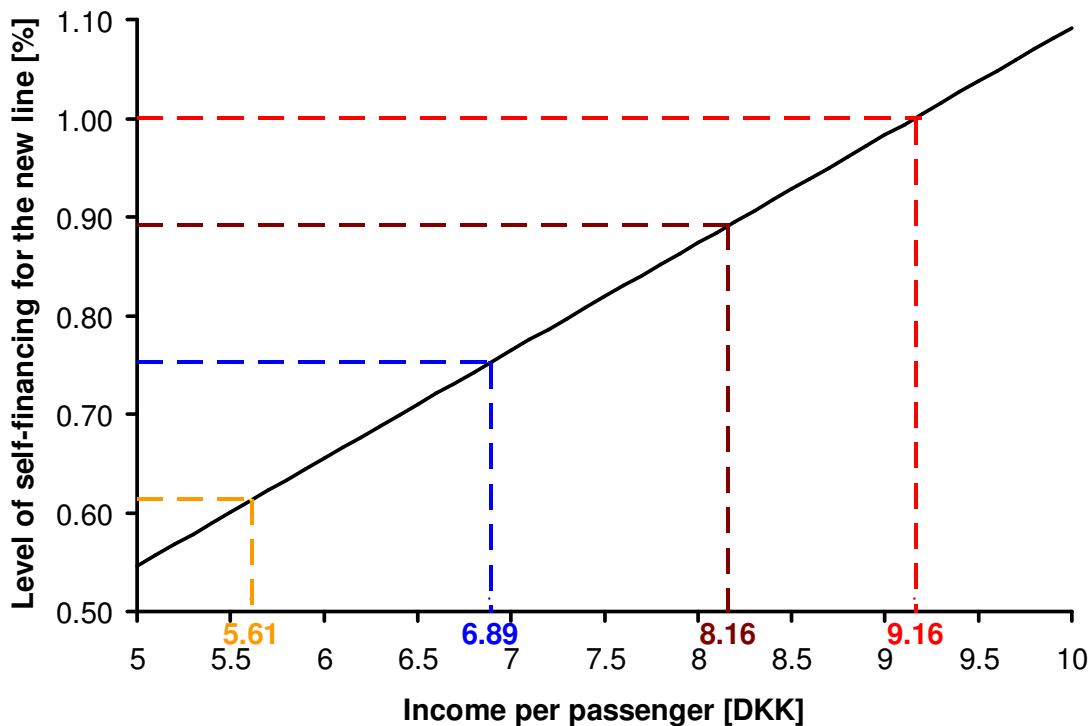


Figure 7.1 – Level of self-financing for the new line as function of income per passenger

7.4 Socio-economic

Socio-economic analysis is considered to be one of the most important approaches to evaluate public transport projects. The socio-economic analysis consists of a Cost-Benefit-Analysis (CBA) which compares the projects annual benefits and disbenefits for the society and the initial cost. In that way the project can be appraised by a socio-economic viability.

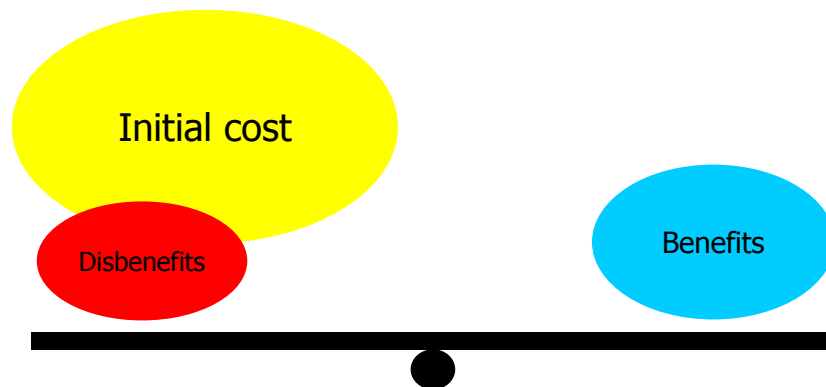


Figure 7.2 – The socio-economic analysis weighs benefits up against disbenefits and cost

When assessing socio-economic impacts of a new public transport line these are the elements that should be featured in the analysis:

- Initial cost
- Operating cost
- Externalities
- Operating and externalities savings from reduced service
- Time savings

7.4.1 Initial cost

The initial cost is the figure that the total benefit should be compared with. Initial cost is estimated as seen in subsection 7.2.1 Initial cost but in the socio-economic analysis there can be implemented the assumption that the cost for cable and pipe rearrangement is only half (see "Note about Socio-economic calculation" for explanation).

	[mil. DKK]
Initial cost	949
Initial cost with ½ cable and pipe cost	786

Table 7.5 – Initial cost for socio-economic analysis (2004-prices)

The figure for the initial cost with half cable and pipe cost in table 7.5 is referred to as the initial cost in year 0 ($Cost_0$ or C_0) in the socio-economic analysis.

7.4.2 Operating cost

Operating cost is a disbenefit because the operation results in a loss. Operating cost is estimated as seen in subsection 7.2.2 Operating cost. Note that operating revenue is not included in the socio-economic analysis since ticket sales are considered to be a redistribution of goods within the society.

7.4.3 Externalities

Externalities are impacts of pollution and accidents as result of the new line only and are considered as a disbenefit. These impacts are calculated through unit costs (c.f. "Unit costs for socio-economic analysis in public transport") (see table 7.6).

	Cost	Quantity	Total
	[DKK per 1000 vehicle km]	[1000 vehicle km]	[mil. DKK]
Noise	60	812.78	0.05
Air pollution	348	812.78	0.28
Accidents	510	812.78	0.41
Total			0.74

Table 7.6 – Externalities for the new line (unit cost for light rail – 1999-prices)

It may be that the introduction of a new high quality public transport system reduces the number of cars. In that case, there is a benefit from less noise, air pollution and accidents caused by cars. However, often the overall reduction in car traffic is low and the benefit from the cars can be neglected in the initial phase.

7.4.4 Operating and externalities savings

Operating and externalities savings from reduced service is only relevant if network adjustments have been made. Normally adjustments have been made to some extent and the reduced operation then determines the savings when multiplied with unit costs (c.f. "Unit costs for socio-economic analysis in public transport") (see table 7.7). Since this is a case of savings it is considered a benefit.

	Cost	Quantity	Total [mil. DKK]
Line 1			
<i>Operation</i>	444 DKK per vehicle hour	1.74 mil. vehicle hours	12.89
<i>Externalities</i>			
<i>Noise</i>	464 DKK per 1000 vehicle km	542 1000 vehicle km	0.25
<i>Air pollution</i>	795 DKK per 1000 vehicle km	542 1000 vehicle km	0.43
<i>Accidents</i>	95 DKK per 1000 vehicle km	542 1000 vehicle km	0.05
<i>Line 1 total</i>			13.62
Line 2			
<i>Operation</i>	444 DKK per vehicle hour	0.52 mil. vehicle hours	3.87
<i>Externalities</i>			
<i>Noise</i>	464 DKK per 1000 vehicle km	163 1000 vehicle km	0.08
<i>Air pollution</i>	795 DKK per 1000 vehicle km	163 1000 vehicle km	0.13
<i>Accidents</i>	95 DKK per 1000 vehicle km	163 1000 vehicle km	0.02
<i>Line 2 total</i>			4.09
Total			17.71

**Table 7.7 – Operation and externalities savings from reduced service
(unit cost for bus – 1999-prices)**

In case of reduced bus service where the whole line is closed down total operation cost for the particular bus line(s) can sometimes be found through key figures for bus service published by the bus authority (e.g. "Key figures for bus service in the greater Copenhagen region"). Using that will make it much easier to determine operating cost and it will give a more accurate result.

7.4.5 Time savings

From the traffic model output the travel time between all model zones can be derived. From that the total travel time in the network can be found and priced. A comparison between the base situation and the scenario situation can then produce the time savings because of the new line. Since the term is time saving it is generally a benefit but closing of too many existing lines in the network adjustments can lead to disbenefits (or at least not an optimal benefit). If that is the case, the overall project is poorly planned and the network adjustments should be reconsidered (more about this in "Note about socio-economic calculations").

The calculation and pricing of travel time in the network are conducted through differentiated values of time affiliated with corresponding parts of a public transport journey (c.f. "Unit costs for socio-economic analysis in public transport") and by using Rule-of-the-half (How to use this procedure and why the differentiated values of time is used see "Sensitivity analysis of socio-economic values of time for public transport projects").

Since the travel time of a public transport journey consist of several different parts (transfer time, waiting time etc.) and since they are priced differently the analysis should rather be conducted in prices instead of time.

The different trip purposes also have different values of time hence they should be calculated separately.

	Trip purpose 1	Trip purpose 2	Trip purpose 3	Total
	[DKK]	[DKK]	[DKK]	[DKK]
Time savings	33,162	4,237	2,702	40,101

**Table 7.8 – Time savings in the network because of the new line (7:00-9:00)
(2004-prices)**

If the traffic modeling only has been performed on a portion of a whole day the time savings must be revalued to daily level and further to yearly level. As described in subsection 7.1.2 Revaluation this is associated with some uncertainties thus a sensitivity analysis will be good practice to perform (see table 7.9).

	Trip purpose 1			Trip purpose 2			Trip purpose 3			Total		
<i>Time savings (7:00-9:00) [DKK]</i>	33,162			4,237			2,702			40,101		
	Low scenario	Applied	High scenario	Low scenario	Applied	High scenario	Low scenario	Applied	High scenario	Low scenario	Applied	High scenario
<i>Share of working day</i>	0.25	0.225	0.2	0.25	0.225	0.2	0.25	0.225	0.2	0.25	0.225	0.2
<i>Time savings (Working day) [1000 DKK]</i>	132.6	147.4	165.8	16.9	18.8	21.2	10.8	12.0	13.5	160.4	178.2	200.5
<i>Working day to year</i>	300	305	310	300	305	310	300	305	310	300	305	310
<i>Time savings (Annual) [mil. DKK]</i>	39.8	45.0	51.4	5.1	5.7	6.6	3.2	3.7	4.2	48.1	54.4	62.2
Total annual time savings [mil. DKK]	45.0			5.7			3.7			54.4		
Sensitivity interval [mil. DKK]	[39.8;51.4]			[5.1;6.6]			[3.2;4.2]			[48.1;62.2]		

Table 7.9 – Annual time savings in the network because of the new line (2004-prices)

7.4.6 Cost-benefit analysis

When all the elements featured in the socio-economic analysis have been determined the cost-benefit calculation can be performed. The last preparation is to choose the calculation year and discount all prices to that year. A comparison between benefits and disbenefits for the new line in first year operation and in comparable price level is good practice to show (see table 7.10):

Elements	mil. DKK
Annual cost for the new line	
Operation	-52.7
Externalities	-0.8
Annual savings for reducing existing service	
Operation + externalities	19.7
Annual time savings	54.4
Total	20.6
Sensitivity interval	[14.3;28.4]

**Table 7.10 – Socio-economic benefits and disbenefits for the new line
(calculation year: 2004)**

From this comparison it is possible to see whether the new line has a positive or negative annual impact on the society. The total figure is regarded as the benefit for the new line and will be implemented in the depreciation procedures as a constant annuity.

How much of the initial cost is earned back in the first year of service is investigated with First Year Rate of Return (FYRR). It is a quick way to see if the project displays socio-economic viability:

$$\text{Formula 7.2} \quad \text{FYRR} = \frac{\text{Benefits}_0}{\text{Cost}_0} \times 100 = \frac{20.6 \text{ mil.DKK}}{786 \text{ mil.DKK}} \times 100 = 2.6 \% [1.8;3.6] \%$$

A large infrastructure project normally has an age-long depreciation period. The Ministry of Transport recommends 50 years for public transport infrastructure projects ("Catalogue of key figures") but other and shorter periods may also be relevant.

The Net Present Value (NPV) and the Benefit-Cost ratio (B/C) are approaches that can be used to investigate public transport projects viability over a depreciation period. The approaches call for a calculation interest rate which in Denmark is determined by the Ministry of Finance to 6 % but otherwise open to analysis since it is determined differently in other countries (c.f. "Light rail project in Copenhagen – the Ring 2 ½ corridor").

The approaches call for a scrap value (also called residual value). A scrap value is the value of the system after ended depreciation (in case the calculation period is shorter

than the lifetime of the project). Following the guidelines from the Ministry of Transport ("Catalogue of key figures – to use for socio-economic analyses in the transport area") the scrap value is the value of the new line after 50 years. If indeed the socio-economic analysis allow for a reasonable maintenance the system will be fully operational after the 50 years and the scrap value can be considered equal to the initial cost (excluding cost for cable and pipe rearrangement since this issue already has been taken into account when the value in the initial cost was reduced by half). The scrap value is thereby a benefit incorporated in the analysis as the value of the initial cost (minus cable and pipe cost) discounted to year 0.

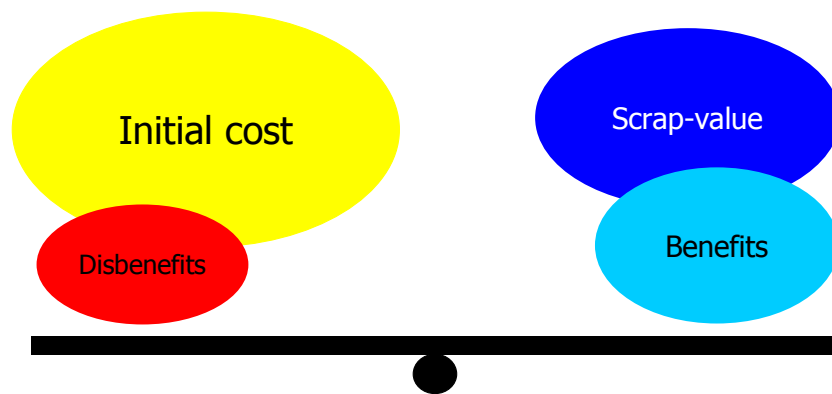


Figure 7.3 – The scrap-value is included in the socio-economic analysis as a benefit

When the above-mentioned preconditions are determined the Net Present Value can be specified (formula 7.3). NPV is a term for the present value of the project; if it is negative the project is not socio-economic viable.

Formula 7.3

$$NPV = \sum_{t=0}^T B_t \cdot (1+r)^{-t} + C_0^x \cdot (1+r)^{-T} - C_0$$

Where:

T is the calculation period

B_t is the total benefits and disbenefits in year t

C_0 is the initial cost in year 0

C_0^x is the initial cost in year 0 excluding cost for cable and pipe rearrangement

R is calculation interest rate

The Benefit-Cost ratio can also be specified (formula 7.4). B/C is a term for the level of viability; if the value is less than 1 the project is not socio-economic viable.

Formula 7.4

$$B/C = \frac{\sum_{t=0}^T B_t \cdot (1+r)^{-t} + C_0^x \cdot (1+r)^{-T}}{C_0}$$

Where:

T is the calculation period

B_t is the total benefits and disbenefits in year t

C_0 is the initial cost in year 0

C_0^x is the initial cost in year 0 excluding cost for cable and pipe rearrangement

R is calculation interest rate

The emerged results can then be presented (see table 7.11).

	Value	Sensitivity interval
NPV [mil. DKK]:	-428	[-527;-305]
B/C:	0.46	[0.33;0.61]

Table 7.11 – NPV and B/C for the new line (calculation period of 50 years)

The development in NPV over time and the discounted benefits compared to the initial cost can be visualized as in figure 7.4.

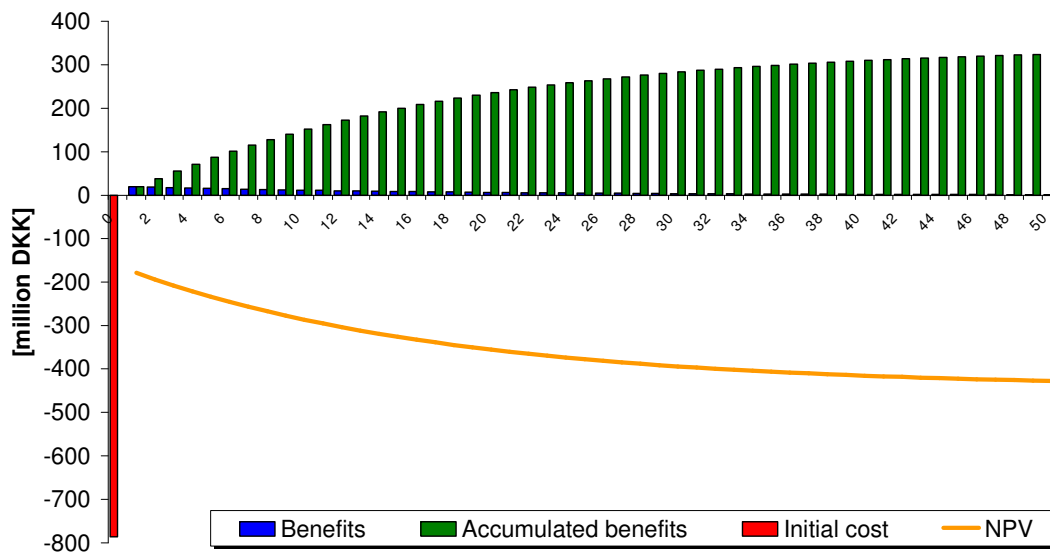


Figure 7.4 – Discounted benefits and development in NPV for the new line over 50 years

In the cost-benefit analysis a calculation period of 50 years is used as the Ministry of Transport recommend. However, shorter periods may also be relevant and this will produce other results (see table 7.12).

	30 years		40 years		50 years	
	Value	Sensitivity interval	Value	Sensitivity interval	Value	Sensitivity interval
NPV [mil. DKK]	-394	[-481;-287]	-415	[-510;-298]	-428	[-527;-305]
B/C	0.50	[0.39;0.64]	0.47	[0.35;0.62]	0.46	[0.33;0.61]

Table 7.12 – NPV and B/C for the new line with different depreciation periods

Rate	Benefits	Cost0	Cost0x	
0.0600	20.6	786	623	
	mil. DKK	mil. DKK	mil. DKK	
	Calculation period (years):			
Year	30	40	50	
1	19.43396226	19.43396226	19.43396226	
2	18.33392666	18.33392666	18.33392666	
3	17.29615723	17.29615723	17.29615723	
4	16.31712946	16.31712946	16.31712946	
5	15.39351836	15.39351836	15.39351836	
6	14.52218713	14.52218713	14.52218713	
7	13.70017654	13.70017654	13.70017654	
8	12.92469485	12.92469485	12.92469485	
9	12.19310835	12.19310835	12.19310835	
10	11.5029324	11.5029324	11.5029324	
11	10.85182302	10.85182302	10.85182302	
12	10.23756889	10.23756889	10.23756889	
13	9.658083858	9.658083858	9.658083858	
14	9.111399866	9.111399866	9.111399866	
15	8.595660251	8.595660251	8.595660251	
16	8.109113444	8.109113444	8.109113444	
17	7.650107023	7.650107023	7.650107023	
18	7.217082097	7.217082097	7.217082097	
19	6.808568016	6.808568016	6.808568016	
20	6.423177374	6.423177374	6.423177374	
21	6.059601296	6.059601296	6.059601296	
22	5.716604996	5.716604996	5.716604996	
23	5.393023581	5.393023581	5.393023581	
24	5.087758096	5.087758096	5.087758096	
25	4.799771788	4.799771788	4.799771788	
26	4.528086593	4.528086593	4.528086593	
27	4.271779805	4.271779805	4.271779805	
28	4.029980948	4.029980948	4.029980948	
29	3.801868819	3.801868819	3.801868819	
30	3.586668697	3.586668697	3.586668697	
31		3.383649714	3.383649714	
32		3.192122372	3.192122372	
33		3.0114362	3.0114362	
34		2.840977547	2.840977547	
35		2.680167497	2.680167497	
36		2.528459903	2.528459903	
37		2.385339531	2.385339531	
38		2.250320312	2.250320312	
39		2.122943691	2.122943691	
40		2.002777067	2.002777067	
41		1.889412327	1.889412327	
42		1.78246446	1.78246446	
43		1.681570245	1.681570245	
44		1.586387023	1.586387023	
45		1.496591532	1.496591532	
46		1.411878803	1.411878803	
47		1.331961135	1.331961135	
48		1.256567109	1.256567109	
49		1.185440669	1.185440669	
50		1.118340253	1.118340253	
Total	mil. DKK	283.55552	309.95372	324.69433

30 years:
Scrap-value:
108.5
NPV:
-393.9
B/C:
0.50
IRR:
0.0212
40 years:
Scrap-value:
60.6
NPV:
-415.4
B/C:
0.47
IRR:
0.0230
50 years:
Scrap-value:
33.8
NPV:
-427.5
B/C:
0.46
IRR:
0.0340

30 years:
Scrap-value: 108.5
NPV: -393.9
B/C: 0.50
IRR: 0.0212
40 years:
Scrap-value: 60.6
NPV: -415.4
B/C: 0.47
IRR: 0.0230
50 years:
Scrap-value: 33.8
NPV: -427.5
B/C: 0.46
IRR: 0.0240

The calculations of the socio-economic results can – if necessary – also be presented e.g. as documentation (see figure 7.5)

Figure 7.5 – Socio-economic calculations

If the project displays non-viability calculating the Internal Rate of Return (IRR) will show at what calculation interest rate the project will be viable (see formula 7.4).

Formula 7.4

$$NPV = \sum_{t=0}^T B_t \cdot (1 + IRR)^{-t} + C_0^x \cdot (1 + IRR)^{-T} - C_0 = 0$$

Where:

T is the calculation period

B_t is the total benefits and disbenefits in year t

C_0 is the initial cost in year 0

C_0^x is the initial cost in year 0 excluding cost for cable and pipe rearrangement

R is calculation interest rate

If the project does not display socio-economic viability it is good practice to find the benefit level for break even. This means finding the annual benefits that are required in order to depreciate the initial cost over the given period. This can profitably be done using the Solver function in a worksheet.

Internal Rate of Return (IRR):	2.4%	[1.5%;3.5%]
--------------------------------	------	-------------

Benefits for break even:	47.7	mil. DKK
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Table 7.13 – Internal Rate of Return and Benefits for break even for the new line (50 years calculation period)

Generally, if a project is socio-economic non-viable it is always good practice to search for reasons. Evaluation of the planning process and reconsidering of debatable choices made along the way can lead to investigations of the impact for deselected options. It can be elements in the physical planning and the timetable planning of the new line as well as network adjustments for existing lines. These investigations can be presented both quantitative (socio-economic calculations of other options) and qualitative (if it requires too much work to alter).

7.5 Car traffic impact

Since the traffic modeling solely is based on a relocation of public transport users the impact for car traffic is ignored. This means that the inconvenience for car traffic because of the new line is also ignored which gives better opportunity for the new line to show good socio-economic results. However, it can be a political priority to focus on public transport and thereby on purpose worsen the conditions a little for car users. In that way the ignored impact on car traffic can be justified.

Another issue that is not handled is that when constructing a brand new high quality public transport line there are potential for existing car users to transfer to public

transport and the new line. Especially if the new line is fast and the roads are congested. For a surface solution like light rail the impact of these transfers are known to be significant. Studies have shown that 5-10 % of a light rail's customers are relocated car travelers (the relocation share) ("Local impacts of light rail"). Using that knowledge a revised number of passengers can be derived from the original that does not incorporate the relocated car users (see formula 7.5).

Formula 7.5

$$Passengers_{Revised} = \frac{Passengers_{Original}}{(1 - RelocationShare)}$$

Using the original number of passengers and income per passenger from subsection 7.3 Operating economy the revised number of passengers and the resulting operating economy can be calculated (see table 7.14).

Relocation share:	0%	5%	7.5%	10%
Daily number of passengers:	15,770	16,600	17,040	17,520
Level of self financing:	75%	79%	82%	84%

Table 7.14 – Revised number of passengers and resulting operating economy for the new line as result of relocated car journeys

Even though the relocation share is based on experience it is not to know whether a new light rail line always will produce such transfers from car traffic. Therefore, the results from table 7.14 should be regarded rather fictitious and curious and not presentable in the same way as the original results.

7.6 Strategic impacts

Strategic impacts are impacts of the project that are not included in the economic analysis; mainly because they are difficult to price and they usually have a long term effect. But that does not mean they are irrelevant. They are actually considered to be of the same – or even greater – magnitude as the short term effects from the economic analysis.

It is good practice to make some qualitative assessments of the strategic impacts when implementing a new line in the public transport system. Some important strategic impacts are:

- Urban development
 - Condensation
 - Development areas
- Property Value
- Car ownership

7.6.1 Urban development

High quality public transport induces urban development in its catchment areas. This can be in form of condensation where the existing urban areas are becoming denser or developing towards more intensive urban functions. Also brand new urban development areas can come into play when getting new high quality public transport. Common for the urban development is that it will not just provide the dynamics of development but it will also in a longer term result in more passengers to the new line; a self-perpetuating effect.

The impact of urban development on the long term is difficult to predict and the assessment of it is therefore usually qualitative. However, it is good practice to point out areas where new development can take place in connections to the new line (see figure 7.6).

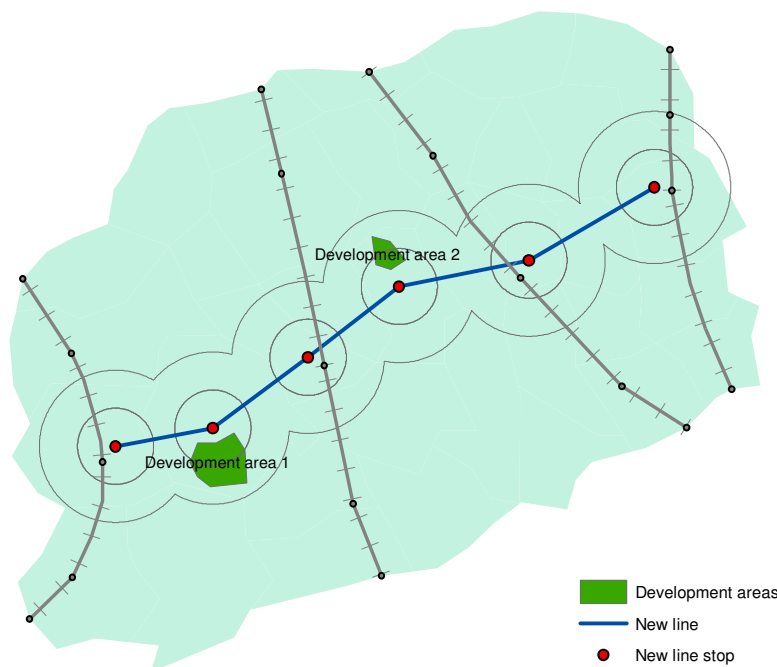


Figure 7.6 – Potential development areas along the new line

7.6.2 Property value

High quality public transport can result in higher value for properties in the vicinity of the new line (e.g. as seen in Ørestad because of Metro line 1). The rise in property value can be assessed qualitative but it is also possible to perform a rough quantitative analysis. To do so, information about the effects on property value from public transport and property values in the affected areas are needed.

The effect on property value (house prices) because of the Copenhagen Metro has been investigated (e.g. "Light rail extension: Ishøj or Brøndby?" and "A hedonic price study of the Copenhagen Metro"). Results are a bit diverging but some tendencies can be extracted and simplified to the assumptions seen in figure 7.7. Since the analysis of property value is a simplified analysis the uncertainties of the assumptions are acceptable.

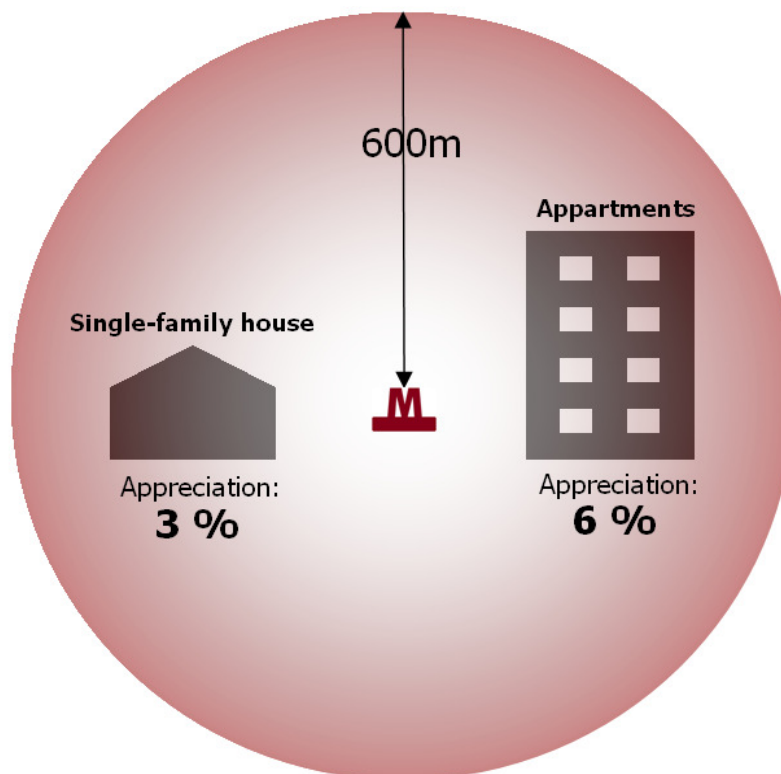


Figure 7.7 – Increase in house prices within catchment area (600m) of new Metro station

Lower quality of transport (like Light rail) is not as attractive as Metro so the increase have to be devalued e.g. by 1/3-1/2.

Areas that were non-station vicinity areas before but henceforth will be serviced by the new line can be identified as well as the local authority the areas belong to (see figure 7.8)

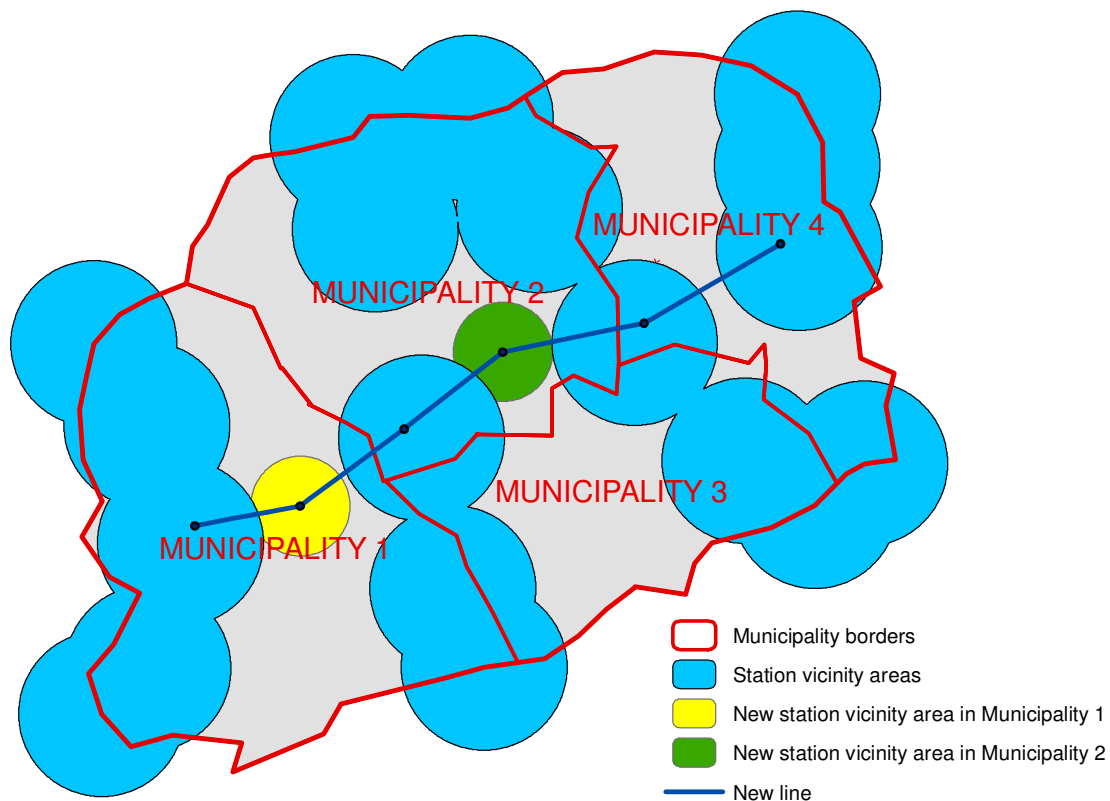


Figure 7.8 – Existing non-station vicinity areas that will be serviced by the new line and the local authority (municipality) they belong to

Number of inhabitants (or households if it is possible) for each new vicinity area can be calculated by overlay analyses and for each local authority the average property value can be found through statistics. From these elements it is possible to calculate an estimate for the increase in house prices because of the new line (see example in table 7.15).

	Inhabitants*	Type of residence	Avg. m2-prices [DKK/m2]	Avg. m2 per person [m2/person]	Per person [DKK/person]	Sum [mil. DKK]	Increase	Total [mil. DKK]
Municipality 1								
Appartments	5,444	56%	16,116	49	796,864	2,450	0.04	98
Single-family houses		44%	14,583	54	789,467	1,870	0.02	37
Municipality 2								
Appartments	6,307	57%	16,244	50	820,300	2,962	0.04	118
Single-family houses		43%	15,110	54	819,878	2,236	0.02	45
Total								
Appartments								216
Single-family houses								82
All								
								299

*Inhabitants in present non-station vicinity areas but futures catchment areas of the new line

Table 7.15 – Example of calculating an estimate for increase in house prices because of the new line (light rail figures)

Be aware that there are so many assumptions in this approach that the resulting figure can be nothing more but a guesstimate but still a good indication of the approximate magnitude of a long term effect.

Be also aware that the increase in property value is based on the effects of lower travel time and there is therefore an element of double calculation from the socio-economic time savings.

7.6.3 Car ownership

The change in car ownership because of new high quality public transport is a long term effect since it is very rare that people e.g. skips their car for public transport (however good it may be) because the car is already bought and paid for. The impact will mostly become apparent in situations where people have an actual choice between public and private transport e.g. when they face a replacement of their existing car which can be far into the future. At this point, there is no useable existing data to base quantitative analysis on so the impact must be described qualitative.

8 Discussion and conclusion

Before making any discussion or conclusions it can be a good idea to list the important characteristics of the new line and results from the project appraisal. Generally, it is good practice to list the figures, findings and conclusions from each part of the investigation to make a summary table (see table 8.1).

Course:	Stop 1 - Stop 6
Length:	7.0 km
Number of stops:	6
Average stop distance:	1.2 km
Mixed traffic driving:	9%
Travel time:	12 min
Average speed:	35 km/h
Line pattern:	All stop service
Frequency:	5 min daytime, 10 min evening/weekends
Transfers:	Rail line 1, 2, 3 & 4
Network adjustments:	Line 1 closed, line 2 cut in service
Daily number of passengers:	15,770
Initial cost:	949 mil. DKK
Operating cost:	52.7 mil. DKK
Ticket revenue:	39.6 mil. DKK
Operating profit:	-13.1 mil. DKK
Level of self-financing:	75%
Annual time savings:	54.4 mil. DKK
Socio-economic benefits:	20.6 mil. DKK
First Year Rate of Return:	2.6%
Net Present Value (50 years):	-428 mil. DKK
Benefit-Cost ratio (50 years):	0.46
Internal Rate of Return (50 years):	2.4%
Property value appreciation:	299 mil. DKK

Table 8.1 – Summary of investigation

8.1 Discussion

The most relevant elements to draw out from the investigation and use in a discussion of the new line's justification is naturally the economic analyses from the project appraisal. However, there are also other elements with importance in decision of the new lines eligibility. Some important elements and what to conclude from them are listed below:

Socio-economic viability Is the project viable or close to being viable and if not does it have positive annual benefits etc.?	Operating economy Is the new line self-financing and if not how much subsidies does it need and how is it compared to other comparable public transport lines (especially the existing bus line if such exists) etc.?
Traffic impacts Does the new line have positive traffic impacts like many passengers and relieving of other public transport lines with capacity problems etc.?	Strategic impacts Does the new line have potential for long term effects like urban development etc.?
General Does the project overall seem to solve general traffic problems of the region? Would it be a political priority? Is similar type of projects successful in other places? Would it be more beneficial to incorporate in a pooling network? Is the socio-economic analysis sufficient etc.?	

As previous mentioned a project that displays good economic results will seldom be reevaluated whereas a project with poor economic results would rightfully undergo further scrutinizing. There is a lot of decision making in the physical planning and in the timetable planning just as the traffic modeling contains many uncertainties. A reevaluation of the choices made along the way and the uncertainties impact is preferable. Ideally, this should be a quantitative procedure altering questionable choices and re-estimating the project appraisal. But this can be extremely resource demanding and a qualitative assessment may therefore be more appropriate. However, it is good practice to at least perform quantitative re-estimations based on the most debatable choices with the assumed highest impact on the project appraisal.

8.2 Conclusion

The conclusion must only contain known material from the investigation and cannot bring forth anything new. Generally it is a summing up of concise conclusions from each chapter and from the discussion.

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